LOSS REDUCTION PROGRAM FOR THE LIBERIA ELECTRICITY CORPORATION

POWER AFRICA TRANSACTIONS AND REFORMS PROGRAM (PATRP)

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ACRONYMS AND ABBREVIATIONS

Acronym	Definition
AC	Alternating Current
ACG	Auxiliary Consumption by Generation
AMI	Advanced Metering Infrastructure
AMR	Automated Meter Reading
ANC	Application for New Connection
ASR	Application for Survey Report
AT&C	Aggregate Technical and Commercial Losses
B&AD	Billing and Analysis Division
B&C	Billing and Collection
CCL	Customer Checking List
CCTV	Close Circuit Television
CFO	Chief Financial Officer
CG	Commercial General
CIS	Customer Information System
CIU	Customer Interface Unit
CMS	Customer Management System
CRF	Connection Request Form
CRM	Customer Relationship Management
CS	Customer Service
CSR	Corporate Social Responsibility
CT	Commercial Technical
DC	Direct Current
DCL	Disconnection Checking List
DMD	Deputy Managing Director
DO	Disconnection Order
DT	Distribution Transformer
EMP	Electricity Master Plan
EMS	Energy Monitoring Section
EMT	Energy Monitoring Team
ERP	Energy Resource Planning
ETF	Electricity Theft Form
FM	Flow Meter
GIS	Geographical Information System
GOL	Government of Liberia
GPRS	General Packet Radio Service

Acronym	Definition
GT	Generator Transformers
GWh	Gigawatt Hour
HFO	Heavy Fuel Oil
HSD	High Speed Diesel
HV	High Voltage
IEC	International Electrotechnical Commission
IMS	Incident Management System
IT	Information Technology
kGal	Kilo Gallon
kWh	Kilowatt Hour
LDC	Load Duration Curve
LEC	Liberia Electricity Corporation
LISGIS	Liberia Institute of Statistics and Geo-Information Service
LL	Load Losses
LL T	Load Losses in Transformers
LLF	Load Loss Factor
LLN	Load Losses in Transmission and Distribution Network
LPRC	Liberia Petroleum Refining Company
LV	Low Voltage
MBS	Metering and billing system
MCC	Millennium Challenge Corporation
MHI	Manitoba Hydro International
MRS	Meter Reading Sheet
MR	Meter Reader
MV	Medium Voltage
MW	Megawatt
MWh	Megawatt Hour
NC	New Connections
NGO	Non-Governmental Organizations
NLL	No-load Losses
NLL T	No-load Losses in Transformers
NS	New Services
O&M	Operation and Maintenance
OD	Operations Division
OHL	Overhead Line
PATRP	Power Africa Transactions and Reforms Program
PoPC	Post-Paid Customer
PrPC	Pre-Paid Customer
RO	Reconnection Order
SOP	Standard Operating Procedure
ST	Sales Technician

Acronym	Definition
T&D	Transmission and Distribution
ThT	Theft Technician
TOU	Time of Use
US	United States
USAID	United States Agency for International Development
USD	United States Dollar
WB	World Bank

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1. EXECUTIVE SUMMARY

The United States Agency for International Development (USAID) contracted the Power Africa Transactions and Reforms Program (PATRP) to undertake a *'Loss Reduction Program for Liberia Electricity Corporation (LEC)'* to estimate the technical and non-technical losses in the LEC network and to recommend activities that will help reduce these losses. The objectives of the program are to:

- Characterize the sources of transmission and distribution losses
    - Identify technical loss sources
    - Identify non-technical loss sources
    - Develop a loss reduction investment plan

- Investigate and propose solutions for discrepancies in fuel measurement and accounting systems

Technical losses are due to energy dissipated in the conductors and equipment used for transmission, transformation, and distribution of electricity. The technical losses are inherent in the system and can be reduced to an optimal level. Non-technical losses include pilferage of electricity due to theft, defective meters, errors in billing and collection, and estimating un-metered electricity supplies.

This assignment consisted of six tasks:

1. Geographical information system (GIS) mapping of the LEC network
2. Estimation of system technical losses
3. Segregation of technical and non-technical losses
4. Evaluation of commercial processes
5. Evaluation of fuel measurement and accounting practices, and
6. Development of a loss reduction plan

The various tasks and deliverables of the assignment are shown in Figure 1-1 below.

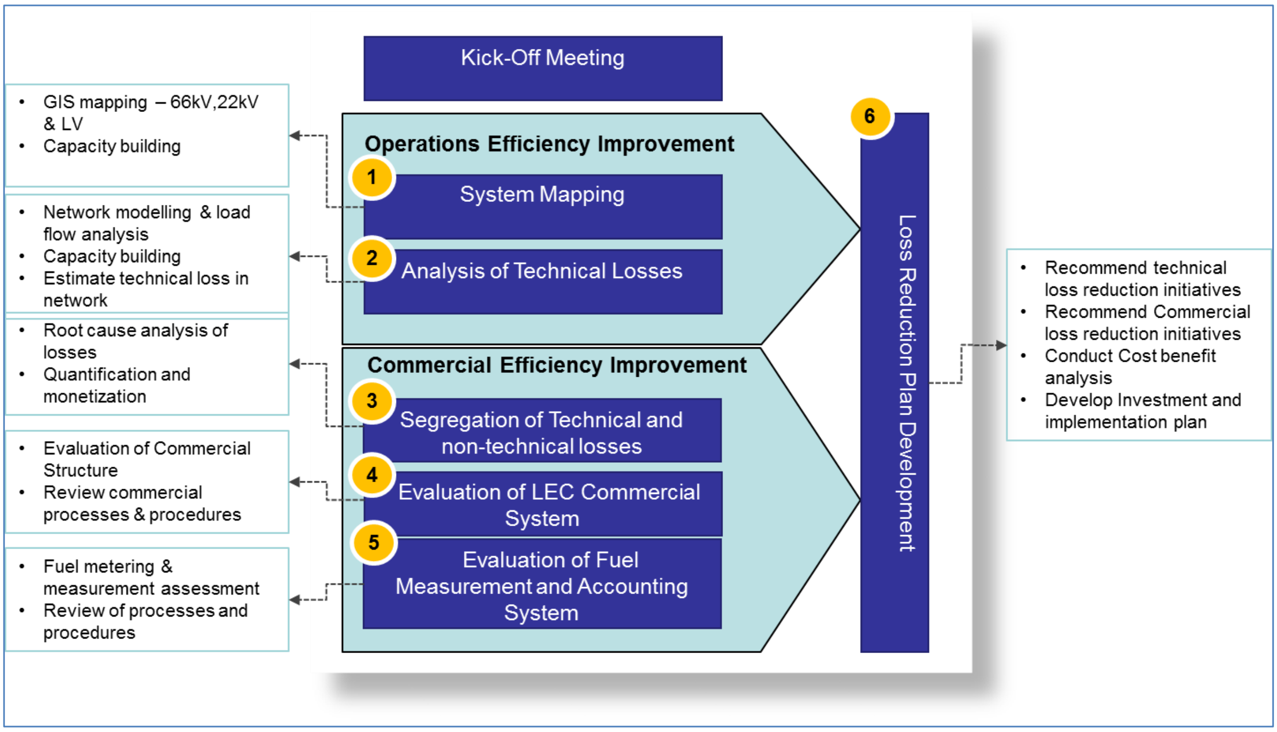

Figure 1-1: Tasks in loss reduction program for LEC

The kickoff meeting for the Liberia Electricity Corporation (LEC) Loss Reduction Program was held on November 9, 2015. It was attended by senior staff from LEC and Manitoba Hydro International (MHI), USAID/Liberia's senior energy advisor, staff from Power Africa's *Beyond the Grid* sub-initiative, and staff of the Power Africa Transactions and Reforms Program (PATRP). A series of meetings, field visits and discussions were held over the next five months to accomplish the objectives of the assignment.

1.1 SYSTEM MAPPING

The first task of the loss reduction program was to create a geographical information system (GIS) map of the LEC network using the ESRI ArcGIS® software tool already available within the LEC Planning Department. The purpose of the system mapping exercise was to characterize the system electrically (not to perform a system inventory), in order to give planning and operations personnel an updated operating map linking their customers to actual geographic locations and the electrical source-side devices from which they are served. The task also involved providing hands-on training to engineers and technicians in the Planning Department in the use of the ArcGIS® software tool, field activities including use of geo-referencing equipment, survey planning, geo-referencing of network nodes, upload of survey data on aggregator server and import of data on the ArcGIS® software for visualization. At the time of ArcGIS® software procurement, some engineers were trained by the supplier. However, due to lack of hands-on training and non-utilization of the tool in day-to-day activities of the Planning Department, the internal capability was lost.

In order to geo-reference all of the relevant electrical components of LEC's sub-transmission and distribution networks, the open source software GeoODK was used, along with three Android phones loaded with ArcGIS® software. This is similar to the approach used on other Liberian infrastructure projects that the World Bank had previously conducted with LISGIS. GeoODK has the advantage of having a customized form for the user interface that simplifies the geolocation process while minimizing user error. In addition, the use of Android phones made the whole process very cost effective, at approximately 100 times less cost than a professional GPS mapping device. During the exercise, more than 227 sectionalizing devices, 1,472 poles, and 1,600 transformers were geo-referenced. A summary of the geo-referenced points is provided in Table 1-1.

Table 1-1: Summary of geo-referenced points

66kV Geo Points			
Gang-switches	Pole	Transformer	
3	27	3	
22kV Geo points			
Substation	Sectionalizing Devices (Line fuse, gang switch, solid blade disconnect)	Pole	Transformer
Bushrod	105	710	955
Capital	70	460	423
Kru Town	41	101	101
Paynesville	52	133	95
Congo Town	9	41	23
400V Geo Points			
Substation	Customer	Transformer	
Via Town	177	17	

Once the data was collected, the creation of various layers of the LEC electrical network commenced. This consisted of a base layer obtained from various sources, including LISGIS, World Bank data, and an open source base layer for the footprint covered by LEC's electrical network. All data points were individually imported by substation and feeder, and the individual geo-referenced data points were then connected in a separate layer to form the inter-connecting feeder conductor. Each of the points was symbolized separately based on the equipment type and with IEC symbols. The ArcGIS® map thus obtained is shown in Figure 1-2.

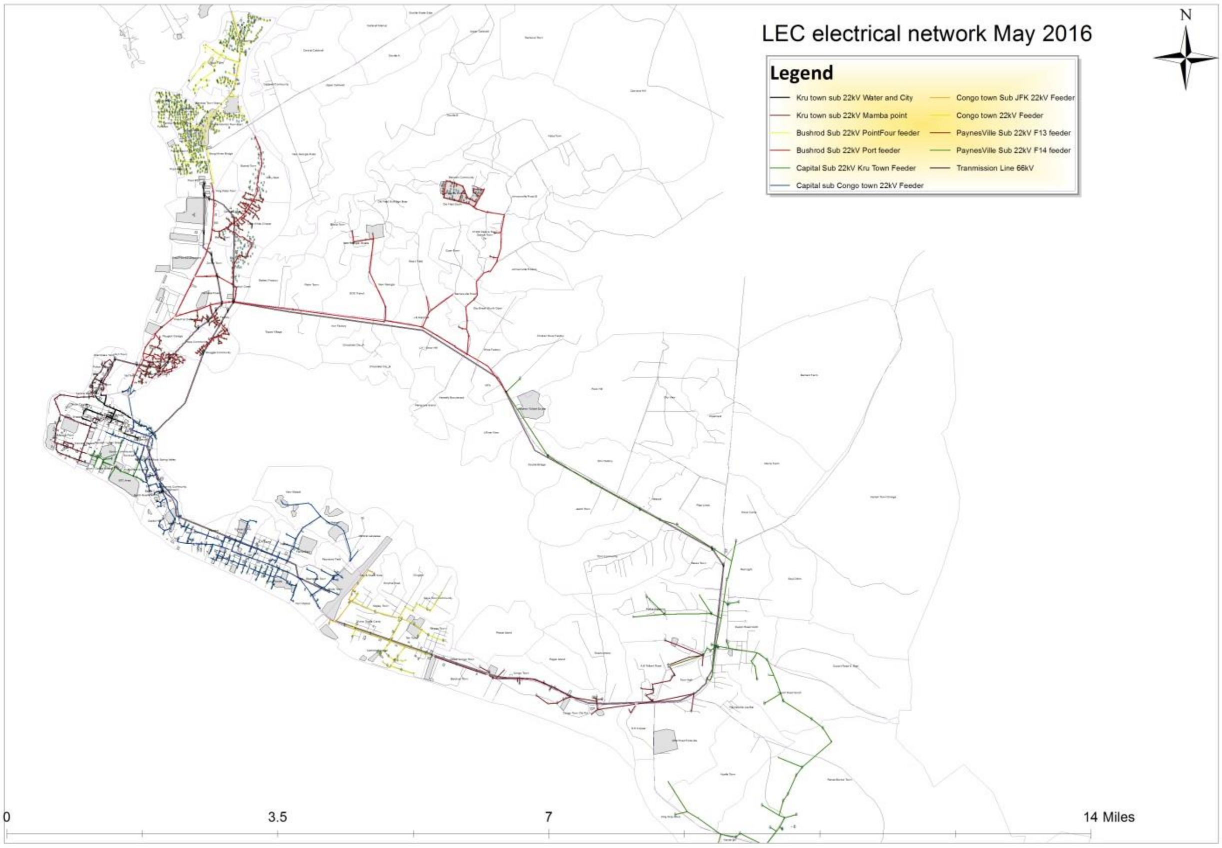

Figure 1-2: LEC ArcGIS® map

The ArcGIS® map for the LEC network developed in this task was used as a base-map for creating the network models on ETAP® (a distribution planning software tool) for the estimation of technical losses.[1]

1.2 LEC SYSTEM TRANSMISSION AND DISTRIBUTION LOSSES

1.2.1 Aggregate technical and commercial (AT&C) losses[2]

Table 1-2 provides fuel supply, consumption, plant efficiency and electricity generation from the LEC generating plants for a one-year period (November 2014 to October 2015). A one-year rolling period is considered, to account for seasonal variations that affect system loss calculations.

[1] PATRP recommends that at least two engineers trained during the exercise should be assigned to use the ArcGIS® software (especially ArcMap and ArcCatalog) to keep themselves conversant with the software. As a sample exercise, the engineers were trained by mapping 150 customer points in the Via Town area. They should continue the exercise and map all the customers on ArcGIS®. Further utilizing the training, the Planning Department should geo-reference the planned and ongoing transmission and distribution line construction.

[2] At present, customers in Monrovia are supplied from the HSD plants in Congo Town, Kru Town and Bushrod generating stations. The World Bank-funded 10 MW plant commenced operation in February 2016 and is excluded from this analysis.

Table 1-2: Generation statistics

	Nov 14	Dec 14	Jan 15	Feb 15	Mar 15	Apr 15	May 15	Jun 15	Jul 15	Aug 15	Sep 15	Oct 15	Total
Fuel Consumed (kGal)	**286**	**257**	**340**	**356**	**457**	**414**	**453**	**430**	**409**	**363**	**420**	**391**	**4376**
Fuel Supplied (kGal)	**305**	**244**	**367**	**343**	**489**	**433**	**429**	**456**	**359**	**438**	**412**	**447**	**4722**
Plant Efficiency (kWh/Gal)	**12.7**	**13.0**	**12.4**	**12.7**	**13.0**	**12.7**	**12.8**	**12.9**	**13.0**	**12.9**	**12.6**	**12.5**	**13.3**
Generation (MWh)	**3625**	**3340**	**4226**	**4509**	**5950**	**5240**	**5787**	**5534**	**5317**	**4683**	**5282**	**4883**	**58376**

As of October 2015, LEC had 36,748 customers comprising of 89.7% residential and 9.7% commercial, with the remaining consisting of the Government of Liberia, NGOs, Public Corporations, LEC and Tax Exempt customers.

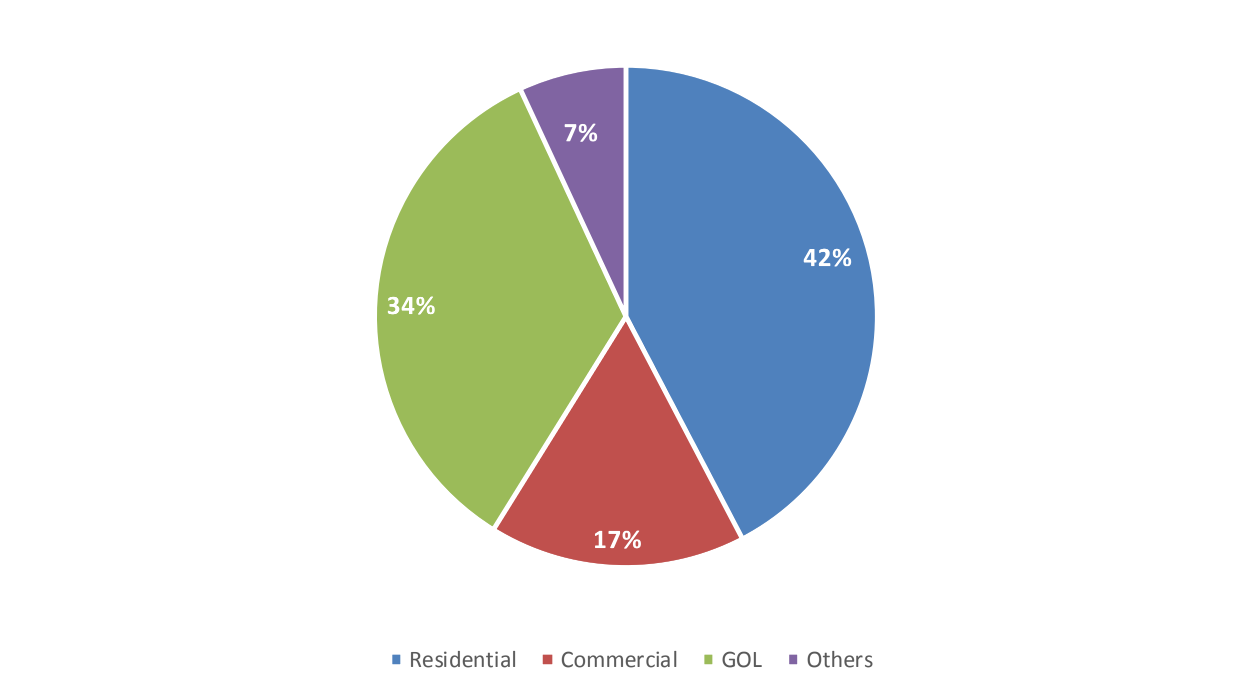

Figure 1-3: LEC Customer sales profile

Figure 1-3 provides the sales profile of LEC customers. Residential customers contribute 42% of sales to LEC, followed by GOL (34%), Commercial (17%), and others (7%). Thus, residential customers comprising almost 90% of the customer base contribute only 42% of the revenue, while a very small number of GOL connections account for over 34% revenue. Almost 10% of commercial connections contribute around 17% to the sales.

Of the total customer base, 90% are pre-payment customers and contribute approximately 60% to sales, while the remaining 10% are post-paid customers and contribute 40% of the sales.

During the period November 2014 to October 2015, only 39,907 MWh were billed to customers, while 58,376 MWh was generated (Table 1-2).

Table 1-3 provides data on number of customers, electricity billing in kWh and USD, and collections during the one-year period of November 2014 to October 2015.

Table 1-3: Billing and collections from Nov'14 to Oct'15

Number of Customers	Billing (kWh)	Per Cust. Ave Consumption (kWh)	Total Billing (USD)	Collection (USD)
36,748	39,907,581	100	20,956,512	23,889,163

Based on the generation data in Table 1-2 and customer sales and collection data in Table 1-3, Figure 1-4 below shows the monthly billing efficiencies, collection efficiencies, and AT&C losses.

Here, billing efficiency means ratio of energy billed to customers to the energy available for sale (in case of LEC , energy generated is equal to energy available for sale), and collection efficiency means ratio of revenue collected from customers to the total billed revenue. Accumulated technical and commercial losses (AT&C) is derived from billing and collection efficiencies and represents technical and non-technical (commercial) losses in an electric system.

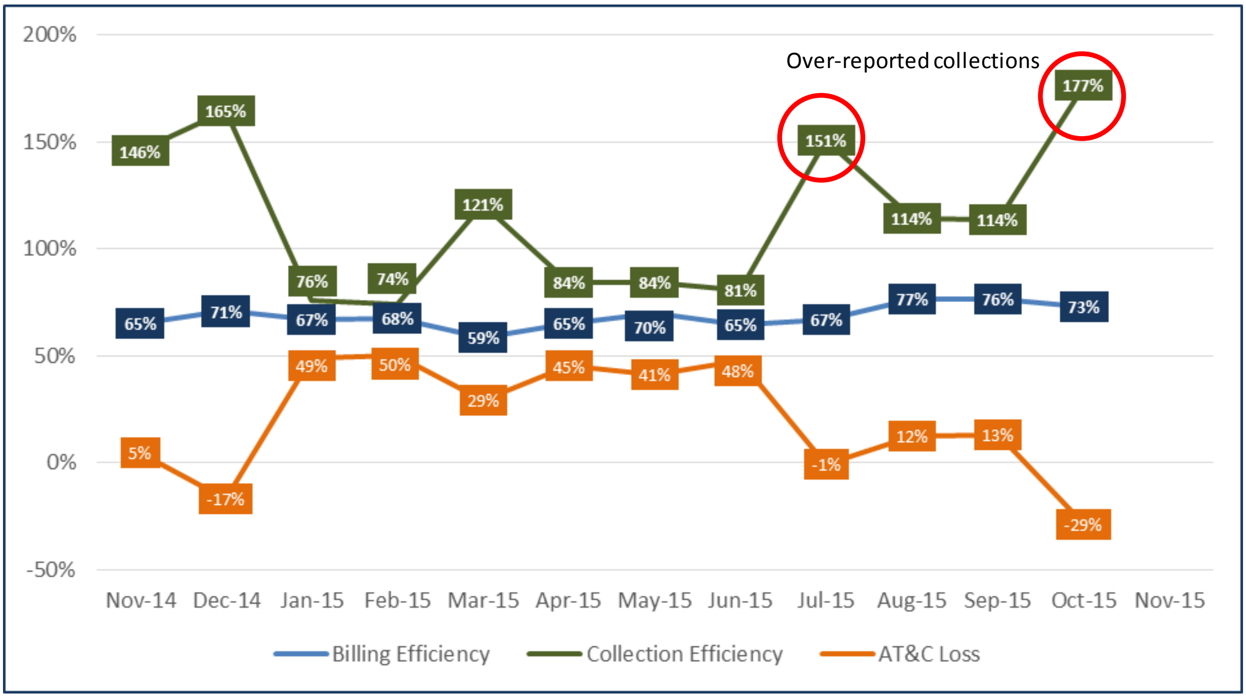

Figure 1-4 : Monthly AT&C losses for one-year period (Nov'14-Oct'15)

During review of the monthly sales and collection details, it was discovered that payments from GOL are irregular. When payments are made from GOL, the collection efficiency rises sharply (as seen in some months in the graphs above). However, in July 2015 and October 2015, the collection efficiency was 151% and 177%, respectively, in absence of large GOL payments. Further, investigation revealed that in these months Liberian dollars were posted as U.S. dollars, an error not detected during audit and reconciliation processes. In July 2015, US$ 2 million pre-payment collection was posted against pre-payment sale of US$ 1.2 million. Similarly, in October 2015, US$ 3 million pre-payment collection was posted against pre-payment sale of US$ 1 million. This resulted in over-reporting of pre-payment collection to the tune of US$ 2.8 million, which if adjusted increases the AT&C losses to over 32% for the period November 2014 to Oct 2015.

Thus, for every 100 units of electricity generated, LEC receives payment for only 68 units, meaning 32 units of electricity are lost due to technical losses in the system and theft, or are simply never collected.

Based on the data provided by LEC for previous years, the table below shows billing efficiency, collection efficiency, and AT&C losses from 2012 to 2015.

Table 1-4: AT&C losses from 2012 to 2015

Parameters	2015 (Nov'14-Oct'15)	FY 2014	FY 2013	FY 2012
Billing Efficiency	68%	75%	71%	77%
Collection Efficiency	100%	94%	107%	82%
AT&C Losses	**32%**	**30%**	**24%**	**37%**
Revenue (millions of $)	$ 21.01	$ 19.6	$ 20.9	$ 16.3

As can be seen in the table, billing efficiency is on a downward trend, which is a real concern for LEC, more so as LEC is planning rapid expansion of its network and intends to grow at a rate of one-hundred percent per annum for the next several years.[3]

1.3 ESTIMATE OF TECHNICAL AND NON-TECHNICAL LOSSES

Technical load losses on system peak were determined by development of appropriate models and power flow studies using ETAP® software. Resulting energy load losses were determined using industry standard techniques for estimating energy losses based upon peak load power flows.

The modelling and power flow studies were conducted for various levels and subsystems to allow for disaggregated technical loss estimates for transmission and distribution networks. The total system technical losses thus estimated are provided in Table 1-5

[3] As per the Electric Master Plan (EMP) update of November 2015, LEC plans to add 139,000 new customers by the end of 2018.

Table 1-5: LEC system technical losses

Network node	Energy loss (%)
Losses in Generation	**5.8%**
Auxiliary Energy Consumption in LEC generators	5.3%
No-load losses in generating transformers	0.5%
Losses in HV network	**2.2%**
No-load losses in HV network	1.0%
Load losses in HV network	1.2%
Losses in MV network	**3.3%**
No-load losses in MV network	2.0%
Load losses in MV network	1.3%
Losses in LV network	**0.62%**
Load losses in LV network	0.62%
Total Technical Energy Losses in LEC network	**11.92%**
Auxiliary Energy Consumption in LEC generators	5.3%
Total Energy No-load Losses	3.52%
Total Energy Load Losses	3.1%

LEC system non-technical losses are estimated at 20.08%, as shown in Table 1-6 below.

Table 1-6: Estimate of non-technical losses in LEC

Description	Losses
Overall System Loss (AT&C)	32%
System technical Loss	11.92%
System non-technical losses	20.08%

PATRP collected data on ongoing theft-reduction activities from the Energy Monitoring Section (EMS) of LEC. EMS is housed in LEC's Generation Department and reports to the Deputy Managing Director (DMD) of Generation. Consistent data on theft-reduction activities is only available for the period following the Ebola outbreak. Therefore, PATRP analyzed the data for the period June 2015 to February 2016. During this period, EMS and Commercial Technical inspected over 5,000 meter installations. Based on the results of these inspections and some sample field survey conducted by the PATRP team, the causes of non-technical losses are shown in Figure 1-5 below.

Here, faulty meters are meters found to be burnt, damaged, or non-working and thus no supply is available to customers.[4] Tampered meters mean that a meter was found to be bypassed (complete or partial) or its circuitry modified so that the meter records less than the consumed electricity. Free power meters are identified as meters that are faulty or non-recording but supply continues to customer premises due to internal circuitry or hardware failure in the meter.

[4] Faulty meters, if detected and replaced in short period of time (i.e. within a day or two), usually do not cause significant revenue loss to a utility. However, in LEC, the detection and replacement of faulty meters takes a long time (usually weeks and in some cases even months), which leads to revenue loss, normally due to bypassing the meter.

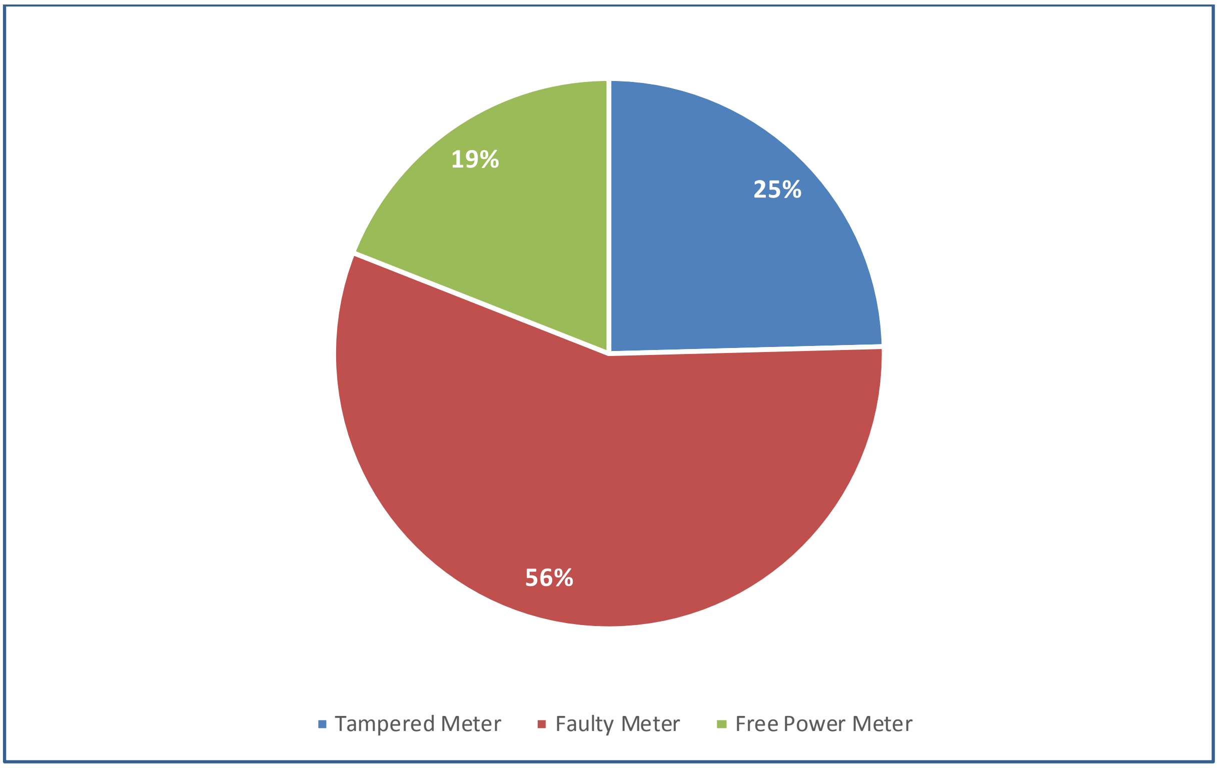

Figure 1-5: Causes of non-technical losses

As shown in the above figure, the chief contributor to non-technical losses is faulty meters, followed by tampered meters and meters giving free power to customers. Though factors related to energy meters seem to be contributing most to the non-technical losses, the PATRP team found that commercial processes implemented in LEC are very weak, which ultimately results in revenue losses with or without meter-related issues.

1.4 RECOMMENDATIONS FOR LOSS REDUCTION AND INVESTMENT PLAN

The PATRP team identified interventions that should be initiated to reduce losses in the LEC system. These interventions relate to many functional areas, including commercial processes, network management and capacity building. The priority actions for loss reduction are listed in Table 1-7 below.

Table 1-7: Priority actions for loss reduction

	Priority Actions
1.	**Realign Commercial Department per organizational and customer needs**
1.a	Restructure with a focus on reducing AT&C losses
1.b	Create large customer group
1.c	Increase focus on community customers
1.d	Give ownership of pre-payment metering system to Commercial Department
1.e	Develop data analytics to support revenue protection
1.f	Improve pre-payment vending system and corporate branding
2.	**Improve current metering system**
2.a	Strengthen meter specifications
2.b	Develop and implement a comprehensive meter sealing system
2.c	Enhance meter testing capabilities
3.	**Implement Automated Meter Reading (AMR)**
3.a	Move all large customers to AMR
3.b	Move feeder and DT metering to AMR
4.	**Implement Energy Balance System**
4.a	Implement EBS at 66kV and 22kV
4.b	Complete DT metering
4.c	Implement customer mapping and enumeration
5.	**Procure a comprehensive commercial IT system**
5.a	Implement CMS and ERP
5.b	Integrate CMS with AMR, Itron Pre-payment system and GIS
5.c	Implement DMS
6.	**Improve fuel accounting system**
6.a	Do periodic cleaning of fuel tanks
6.b	Calibrate and test flow meters periodically
7.	**Build capacity of staff**
7.a	Train staff on meter data analysis, meter testing, and revenue protection
7.b	Train staff on electricity balance calculations and troubleshooting
7.c	Conduct exposure visits to utilities with strong commercial systems
7.d	Provide more training on ArcGIS® and network modelling & simulations
7.e	Build capacity in customer care and outreach
7.f	Training on O&M and safety

While some of the priority actions require minimal investments (e.g. adopting new procedures, changing present procedures, or restructuring of departments), others require substantial capital investment. Capital investments are needed for enhancing testing capabilities, implementing AMR, implementing an energy balance system, procuring a comprehensive IT system, and building capacity of staff. These investments are summarized in Table 1-8 below.

Table 1-8: LEC investment requirement

Investment	2016-17	2017-18	2018-19	2019-20	2020-21	Total
Enhance Meter Testing Capabilities	$ 330,000	$295,000				$625,000
Implement AMR System		$1,250,000				$1,250,000
Implement Energy Balance	$ 160,000	$90,000	$109,000	$75,000		$434,000
Procure Comprehensive IT System	$6,000,000	$6,000,000				$12,000,000
Capacity Building		$2,421,300	$421,300	$210,650	$105,325	$3,158,575
Total	**$6,490,000**	**$10,056,300**	**$530,300**	**$285,650**	**$105,325**	**$17,467,575**

PATRP estimates that LEC needs to invest approximately $17.5 million in loss reduction measures over the next five years to make the utility sustainable. Some of the investments included in the above table are already under consideration and should be expedited. For instance, the World Bank is already supporting the procurement of a comprehensive IT system, and MCC is assisting in the development of a training center within LEC. For other investments, LEC should work with the donor partners already involved in the sector for funding.

By implementing the recommended priority actions, LEC should be able to reduce AT&C losses to 11%-12% in the next four to five years, as shown in Figure 1-6.

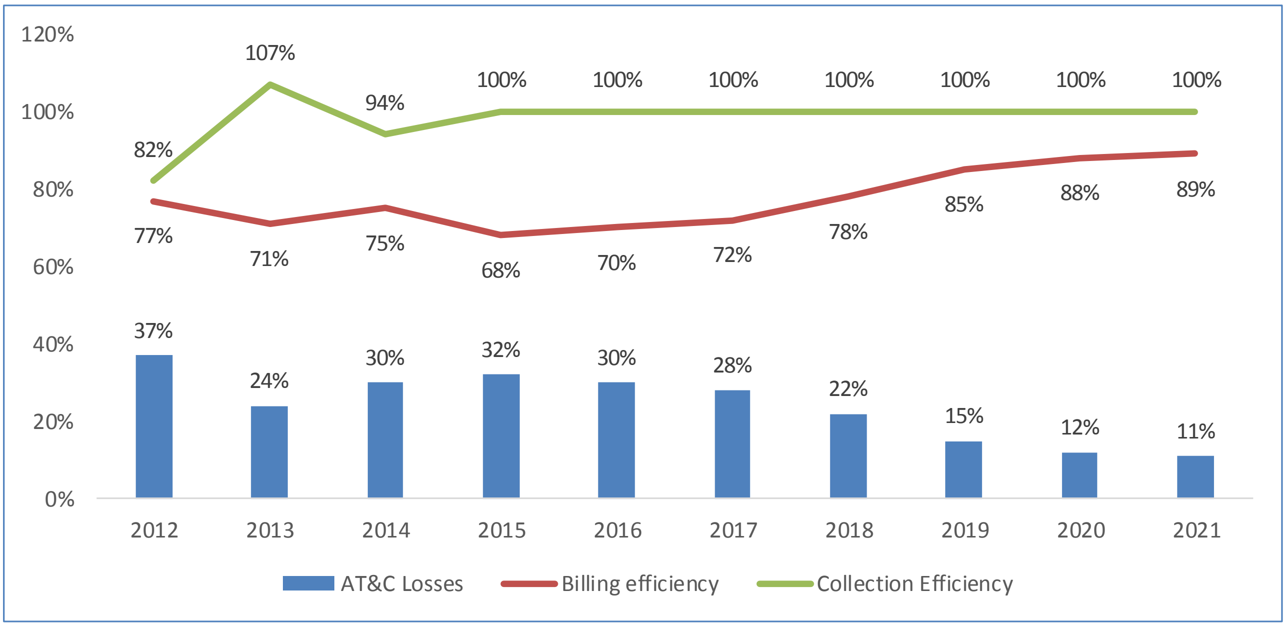

Figure 1-6: Loss reduction trajectory

As more than 90% of customer connections are planned to remain on a pre-paid metering system, the collection efficiency will be around 100% in the coming years, as well. The billing efficiency will improve over the years as the recommended initiatives are implemented. It may appear that four years is a long timeframe for reducing losses to 11%-12% for a small utility with just 36,000 connections. However, it should be considered that LEC plans to double its customer base every year for the next couple of years, expanding its services to areas beyond the Greater Monrovia region. This expansion will have a bearing on the resources available for implementing the priority actions.

Additionally, the current management contract for LEC is coming to an end in December 2016, and a new management contractor will start services in mid-2017. This transition may slow the implementation of some of the priority actions. Thus, the actual impact of loss reduction will be visible from financial year 2018.

2. SYSTEM MAPPING

2.1 INTRODUCTION

The goal of the system mapping task was to characterize the LEC electricity generation, transmission, and distribution systems electronically utilizing the ESRI ArcGIS® mapping application and software. It consisted of mapping the entire 66kV Sub-Transmission network and the 22kV Distribution network by geocoding the important equipment throughout LEC's electrical network. The geocoding exercise allows LEC to characterize the system electrically (not to perform a system inventory), and provides planning and operations personnel to have an updated operating map that links customers to actual geographic locations and the electrical source-side devices from which they are served.

The task also consisted of training the LEC planning team engineers and technicians to perform the geocoding task using cost-effective mechanisms of collecting, aggregating, and publishing the data onto the ArcGIS® system.

At present, LEC has the ArcGIS® Desktop Suite (v 10.2.1) installed on three desktops in the Planning Department. At the time of software purchase, the supplier had provided training to some of the engineers. However, the training was not put to regular use, resulting in loss of capability amongst the LEC engineers. At the inception of the task, the PATRP team provided a three-day hands-on field orientation training to select planning engineers to refresh their earlier training and to prepare them for the activities to be carried out.

2.2 COLLECTION OF GIS DATA

A base-map that shows the physical location of Monrovia and some of its surrounding areas was obtained from the Liberia Institute of Statistics and Geo-Information Service (LISGIS). Some of the other supporting layers showing major roads and all Monrovia buildings were obtained from publicly available mapping done by the World Bank and African Development Bank. These sets of layers formed the base geographic and physical attribute layers of Monrov*ia*.

In order to geo-reference all the relevant electrical components of LEC's sub-transmission and distribution network, the open source software GeoODK was obtained and uploaded to three Android phones, along with the customized electrical system mapping form. This is similar to the approach used on other Liberian infrastructure projects that the World Bank had previously undertaken. GeoODK has the advantage of having a customized offline form that simplifies the geolocation encoding process, while minimizing user error. In addition, the use of the GIS capability of an Android phone made the whole process a very cost-effective one (about 100 times less expensive than a professional GPS mapping device). Below, Figure 2-1 displays a representative set of screens that the teams used to collect the data:

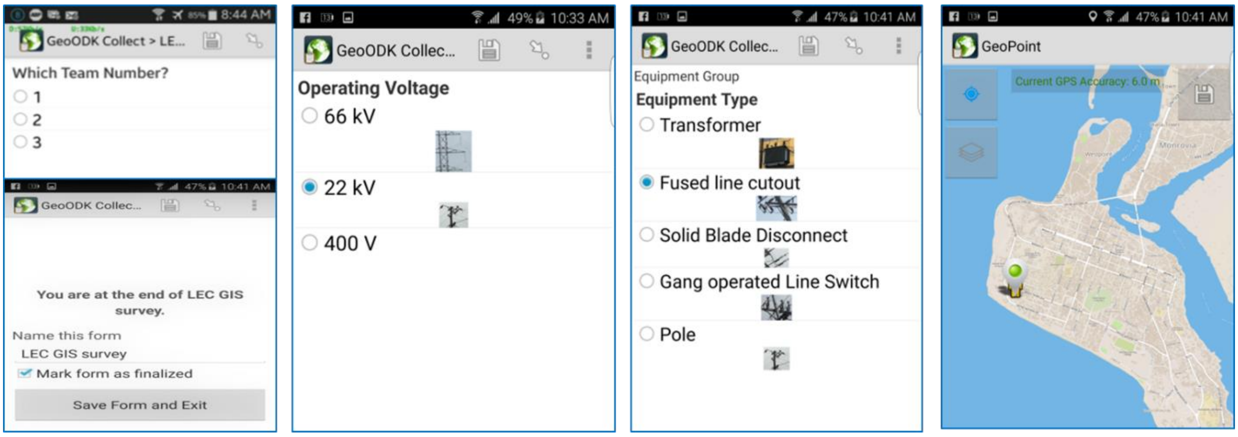

Figure 2-1: GeoODK input screen snapshots on Android phone used by field teams

An additional advantage of using GeoODK as the collection application was its capability of including offline layers within the app, thus allowing field geocoders to work without any mobile data network connectivity. This feature allowed an accurate collection of data points that were not physically accessible, such as the 66kv tower locations situated on the remote marshlands as well as secured areas like the U.S. embassy. Creation of forms that helped in the capture of various information was done using XlsForms. This enabled the field survey teams to quickly collect the geo-reference points as shown in the snapshots above.

Figure 2-2: Field team conducting geo-referencing exercise

Table 2-1 provides the summary of LEC network points geo-referenced during the field exercise.

Table 2-1: Summary of geo-referend points

66kV Geo Points			
Gang-switches	Pole	Transformer	
3	27	3	
22kV Geo points			
Substation	Sectionalizing Devices (Line fuse, gang switch, solid blade disconnect)	Pole	Transformer
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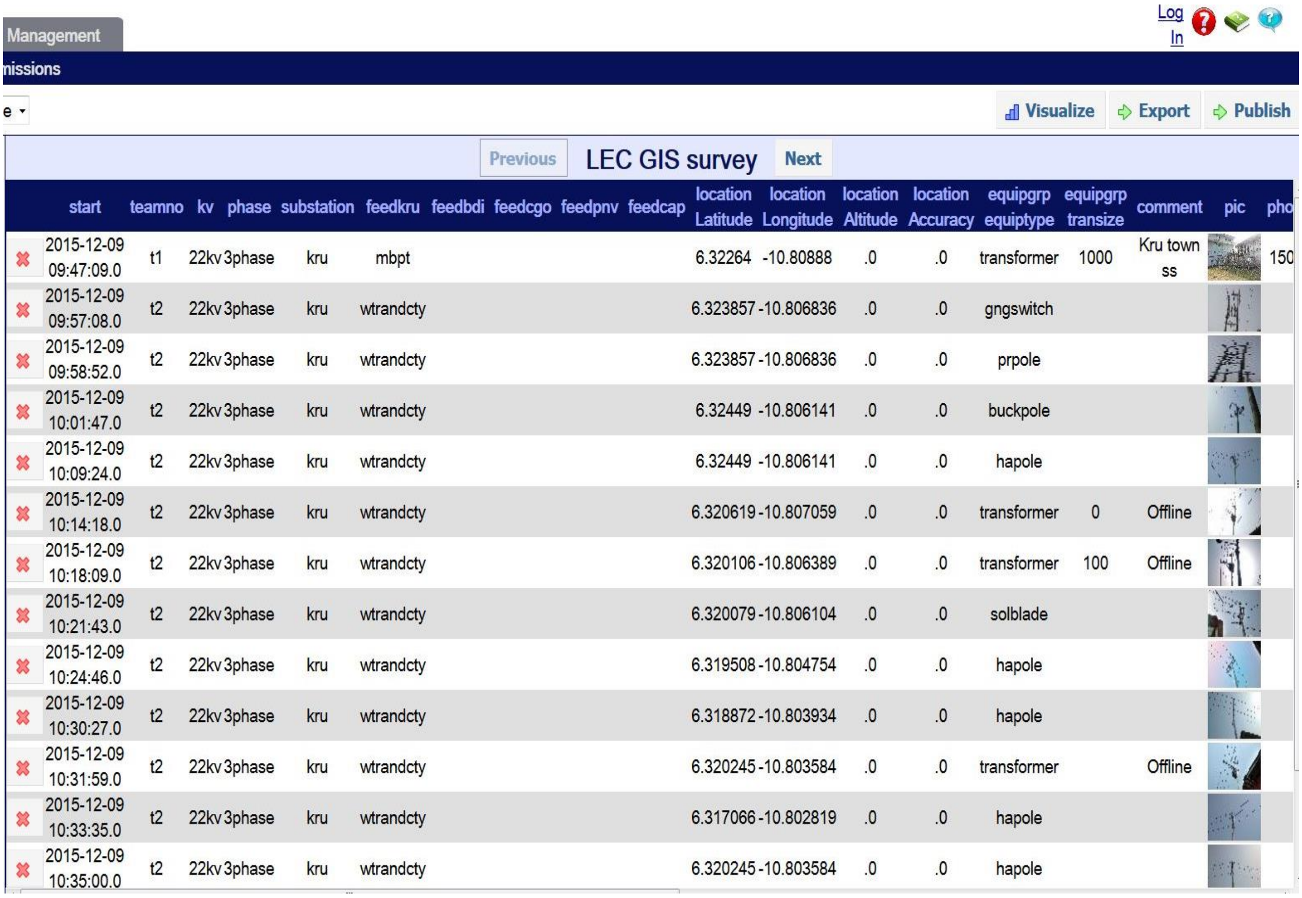
Congo Town	9	41	23
400V Geo Points			
Substation	Customer	Transformer	
Via Town	177	17	

2.3 AGGREGATION AND VERIFICATION

At the end of each day of field survey, data was uploaded to a data aggregation server that was created and set up using ODKAggregate, running on an Ubuntu Linux virtual machine. A WiFi hotspot at the PATRP field activity sub-contractor's office was used to upload the data seamlessly using the Android phones. This ensured a robust collection of the data points after each day of work. The two-way handshake maintained between the Android application and the ODK aggregate software enabled complete data collection and prevented duplication or loss of the data.[5] A further advantage of ODKAggregate was that it allowed visualization of the data, along with an ability to export to an Excel file. This allowed offline quality control as well as monitoring of incremental work, which was collected and uploaded. The ODK Aggregate server and tools are shown in Figure 2-3 and Figure 2-4.

[5] A large amount of valuable network geo-referencing data was collected during the task, and it is important that LEC protect against loss of the data. One of the ways to protect the data is to host the ArcGIS® software on the LEC server. At present, the ArcGIS® software is only a desktop version and cannot be hosted on the server. LEC should immediately provision for procuring a server version of the ArcGIS® software tool. Until the server version of the software is purchased and installed, updates and modifications to the ArcGIS® map should be performed on only one desktop to ensure consistency an d prevent conflicting map representations.



	start	teamno	kv	phase	substation	feedkru	feedbdi	feedcgo	feedpnv	feedcap	location Latitude	location Longitude	location Altitude	location Accuracy	equipgrp equiptype	equipgrp transize	comment	pic	pho
	2015-12-09 09:47:09.0	t1	22kv	3phase	kru	mbpt					6.32264	-10.80888	.0	.0	transformer	1000	Kru town ss		150
	2015-12-09 09:57:08.0	t2	22kv	3phase	kru	wtrandcty					6.323857	-10.806836	.0	.0	gngswitch				
	2015-12-09 09:58:52.0	t2	22kv	3phase	kru	wtrandcty					6.323857	-10.806836	.0	.0	prpole				
	2015-12-09 10:01:47.0	t2	22kv	3phase	kru	wtrandcty					6.32449	-10.806141	.0	.0	buckpole				
	2015-12-09 10:09:24.0	t2	22kv	3phase	kru	wtrandcty					6.32449	-10.806141	.0	.0	hapole				
	2015-12-09 10:14:18.0	t2	22kv	3phase	kru	wtrandcty					6.320619	-10.807059	.0	.0	transformer	0	Offline		
	2015-12-09 10:18:09.0	t2	22kv	3phase	kru	wtrandcty					6.320106	-10.806389	.0	.0	transformer	100	Offline		
	2015-12-09 10:21:43.0	t2	22kv	3phase	kru	wtrandcty					6.320079	-10.806104	.0	.0	solblade				
	2015-12-09 10:24:46.0	t2	22kv	3phase	kru	wtrandcty					6.319508	-10.804754	.0	.0	hapole				
	2015-12-09 10:30:27.0	t2	22kv	3phase	kru	wtrandcty					6.318872	-10.803934	.0	.0	hapole				
	2015-12-09 10:31:59.0	t2	22kv	3phase	kru	wtrandcty					6.320245	-10.803584	.0	.0	transformer		Offline		
	2015-12-09 10:33:35.0	t2	22kv	3phase	kru	wtrandcty					6.317066	-10.802819	.0	.0	hapole				
	2015-12-09 10:35:00.0	t2	22kv	3phase	kru	wtrandcty					6.320245	-10.803584	.0	.0	hapole				

Figure 2-3: ODK Aggregate listing of geo-referenced points

Figure 2-4: Visualization of geo-referenced points using ODK Aggregate and Google maps

2.4 PUBLISHING AND TRAINING

Once the data was collected, the creation of various layers of the LEC electrical network commenced. This consisted of a base layer obtained from various sources, including LISGIS, World Bank data, and an open source base layer for the footprint covered by LEC's electrical network. All data points were individually imported by substation and feeder, and the individual geo-referenced data points were then connected in a separate layer to form the inter-connecting feeder conductor. Each of the points was symbolized separately based on the equipment type and with IEC symbols. The separate layers allow users to visualize each feeder along with its associated equipment points. Thanks to the collection of snapshots of all equipment that was geo-referenced, users can identify and verify each of the data points, which is invaluable in determining transformer rating as well as status of the connection of the equipment. It also serves as a visual aid to determine whether equipment is offline or not yet connected due to recent installation. Figure 2-5 below shows the LEC network map developed on ArcGIS® under the task. Each feeder in the map has been shown by a different color for better visualization and identification.

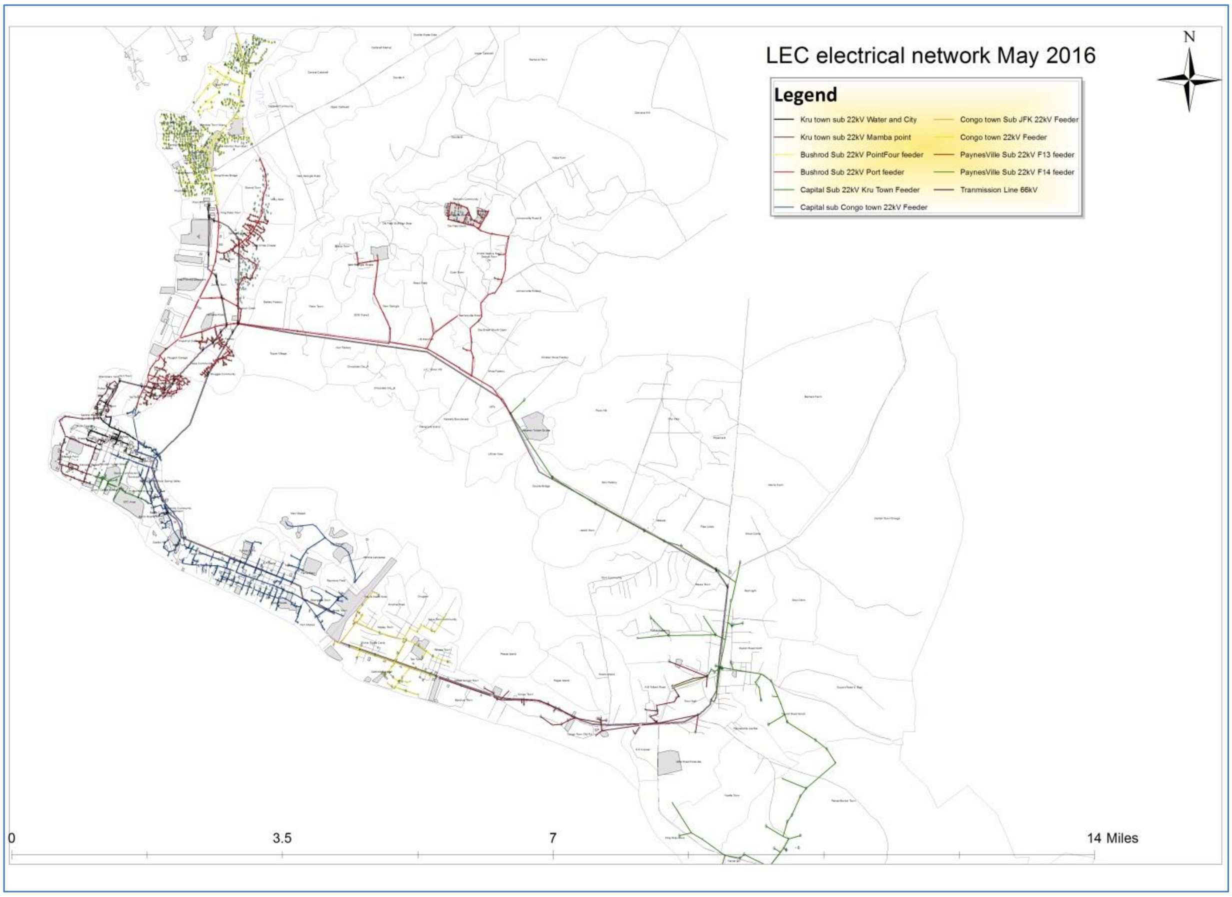


Figure 2-5: LEC ArcGIS® map with each feeder in different color

The ArcGIS® network model helped develop the ETAP® power flow analysis model for estimation of technical losses in the LEC network. To facilitate the ETAP® model, the GIS survey captured important network attributes, such as transformer types and ratings, line ratings, sectionalizers, etc. Each attribute was used as a label to facilitate the creation of the ETAP® model.

2.5 CAPACITY BUILDING

The PATRP team provided hands-on training to engineers and technicians in LEC's Planning Department. The training included the following aspects of GIS activities:

- Orientation and basic training of ArcGIS® use and operations
- Field Geo-referencing survey planning and preparation
- Training on open source GeoODK software use and creation of customized forms for field survey
- Hands-on training on geo-referencing LEC network by using android mobile phones with ArcGIS® software and uploading survey data on aggregator server that was created and setup using ODKAggregate, running on an Ubuntu Linux virtual machine
- Data point migration, editing and export to AutoCAD (the training also included scenarios that focused on continuing addition of the ArcGIS® map including importing data from other GIS devices and creating layers to reflect the collected data)
- Procedures for updating and maintaining LEC network map in ArcGIS® software

The hands-on training continued for five months during the field surveys. At the end of the GIS task, a separate five-day training was delivered to twelve (12) LEC engineers. The training included creating a separate layer from collected data points and exporting that into a geodatabase.

Figure 2-6: ArcGIS® training, Q&A session

Figure 2-7: GIS training in progress

2.6 RECOMMENDATIONS

PATRP recommends the following for continuing effective usage of the ArcGIS® suite for planning purposes:

- Procure a server version of ArcGIS® software and host it on an LEC server to protect against data loss.
- Keep using the ArcGIS® software, especially ArcMap and ArcCatalog.
- Finish connecting the 150 data points from the Via Town exercise to help the relevant engineers in strengthening their ArcGIS® knowledge.
- Modify the data points in the ETAP® model to include any updated information that can be used to verify transformer sizes, connectivity as well as feeder configuration.
- All new data points for geo-referencing such as the Kakakta upgrades as well as all the new installed equipment should be reflected in the ArcGIS®.
- Use tutorials and books provided to hone and strengthen the knowledge of ArcGIS®. Practice using the various portions of the software to cement understanding.
- The ArcGIS® map can be effectively used to reflect changes automatically by visual changes in the color, shape and size of the equipment such as gang-operated switches based on their status.
- Designate two engineers with the appropriate security rights for maintenance and upkeep of the map once the ArcGIS® server is installed.
- Prior to the installation of the ArcGIS® server, only one machine should be used to update the map to avoid conflicting and staggered updates of separate client maps that may cause difficulty in final migration to the server.

3. ANALYSIS OF TECHNICAL LOSSES

3.1 INTRODUCTION

The objective of this task was to estimate the technical losses at system peak in the LEC network by modelling the network using the ETAP® software tool. PATRP opted to use the ETAP® tool as it is already available in LEC's Planning Department and will support capacity building of planning engineers during the execution of the task.

Technical losses are due to energy dissipated in the conductors and equipment used for transmission, transformation and distribution of electricity. The technical losses are inherent in the system and can be reduced to an optimal level. The PATRP team used in-built network diagrams, the ArcGIS® map developed during this assignment, and field visits to collate data needed for modelling the LEC network on ETAP®.

The following sections describe the methodology used for estimating these losses, collection of data, modelling of LEC network, load flow analysis, and results obtained.

3.1.1 Technical losses

There are two main components of technical losses in a transmission and distribution networks:

- **No-Load Losses:** These losses are fixed and do not depend on the load. These losses arise from the standing, or iron, losses of the network transformers (substation and distribution).
- **Load Losses:** These losses depend on the electricity being supplied through the transmission and distribution networks. These losses are proportional to square of the current being supplied through the network equipment such as transmission and distribution lines, substation and distribution transformers, etc. These losses are also known as copper losses, or I^2R losses.

There is also an inevitable "third component" of loss, which is the inevitable difference between electricity generated and electricity delivered to the end-users due the auxiliary consumption by generating plants and network facilities.[6]

3.1.2 Electricity Balance

The following equilibrium equations form the basis of system electricity balance, and must be understood for any power system to maintain continuous balance between its supply and demand:

[6] While the auxiliary consumption by transmission and distribution facilities (e.g. substation lighting, electricity consumed in substation secondary/LV circuits etc.) are not significant and thus sometimes neglected for practical purposes, the electricity consumption by generating plants may contribute a notable difference to an electricity balance.

Gross Generation = Gross Demand; [1]

or,

Gross Generation = Net Demand + Technical Losses + Auxiliary Consumption [2]

A more visual representation of the structure of electricity balance can be schematically presented in Figure 3-1.[7]

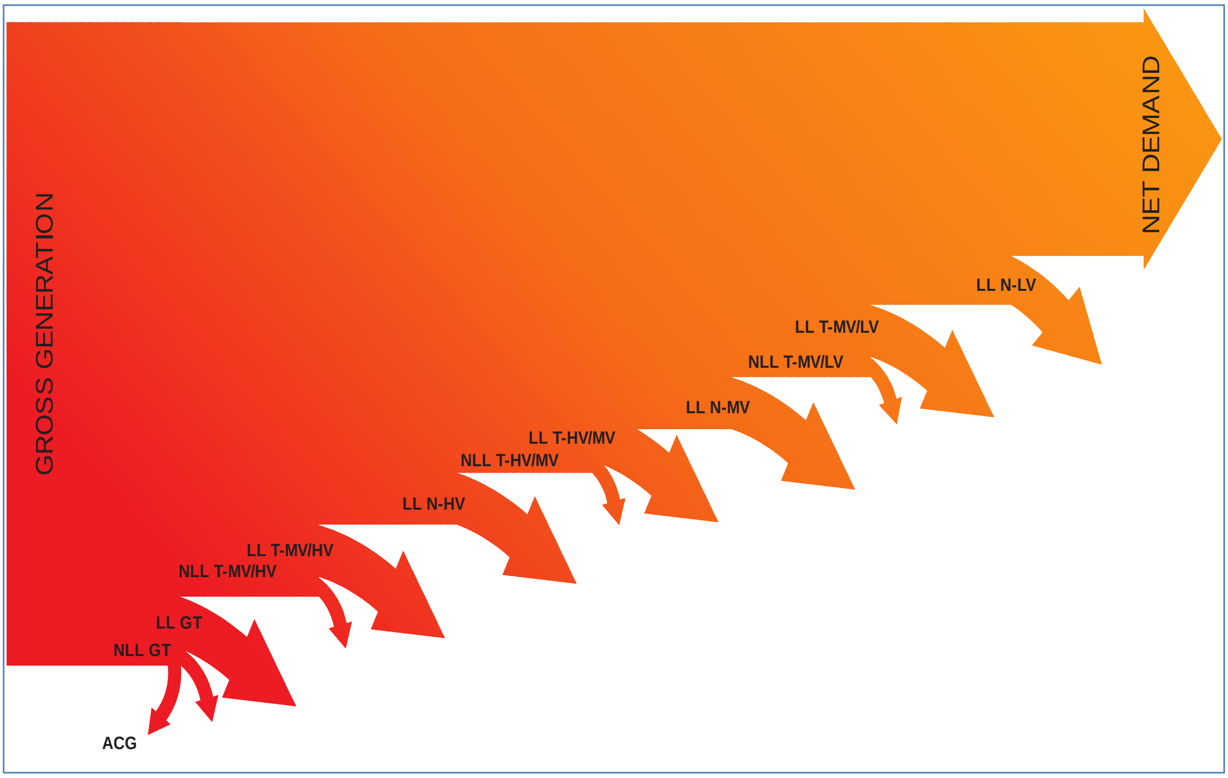


Figure 3-1: Power system energy balance diagram

Legends for above figure:

ACG	Auxiliary Consumption by Generation	NLL T-XX/XX	No Load Losses in Transformers
NLL	No Load Losses	LL T-XX/XX	Load Losses in Transformers
LL	Load Losses	LL N – XX	Load Losses in transmission and distribution network
GT	Generator Transformers		
HV	High Voltage (66kV)		
MV	Medium Voltage (22 kV)		
LV	Low voltage (0.4/0.23 kV)		

[7] The diagram is not to scale.

3.1.3 Technical Loss Calculation Methods

Technical loss calculation methods can be summarized as follows:

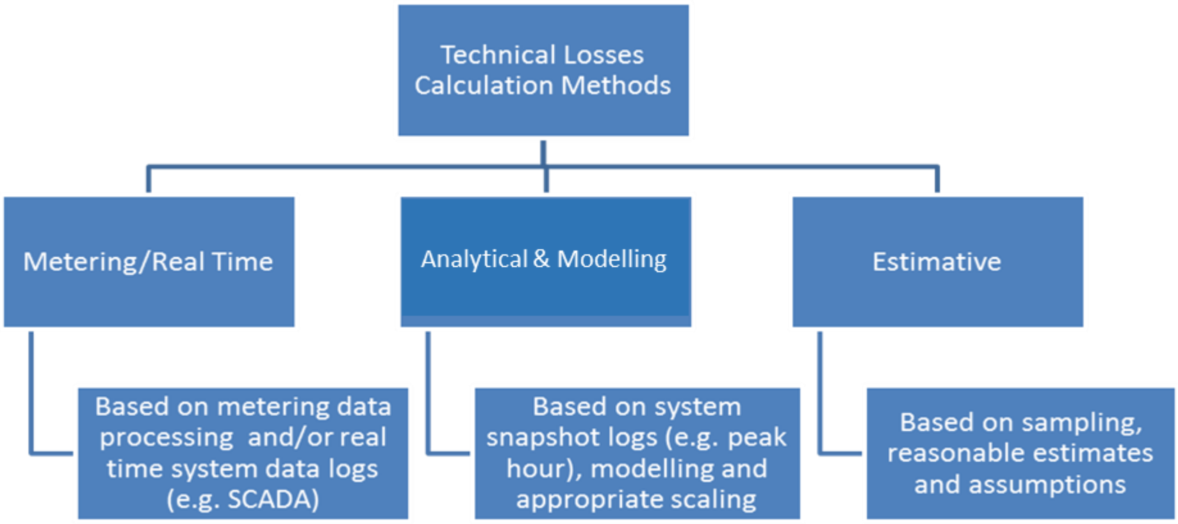


Figure 3-2: Technical loss calculation methods

Selection of the technical losses calculation method is iterative and depends on availability of data and its reliability. The algorithm for selecting a technical loss estimation method is provided below.

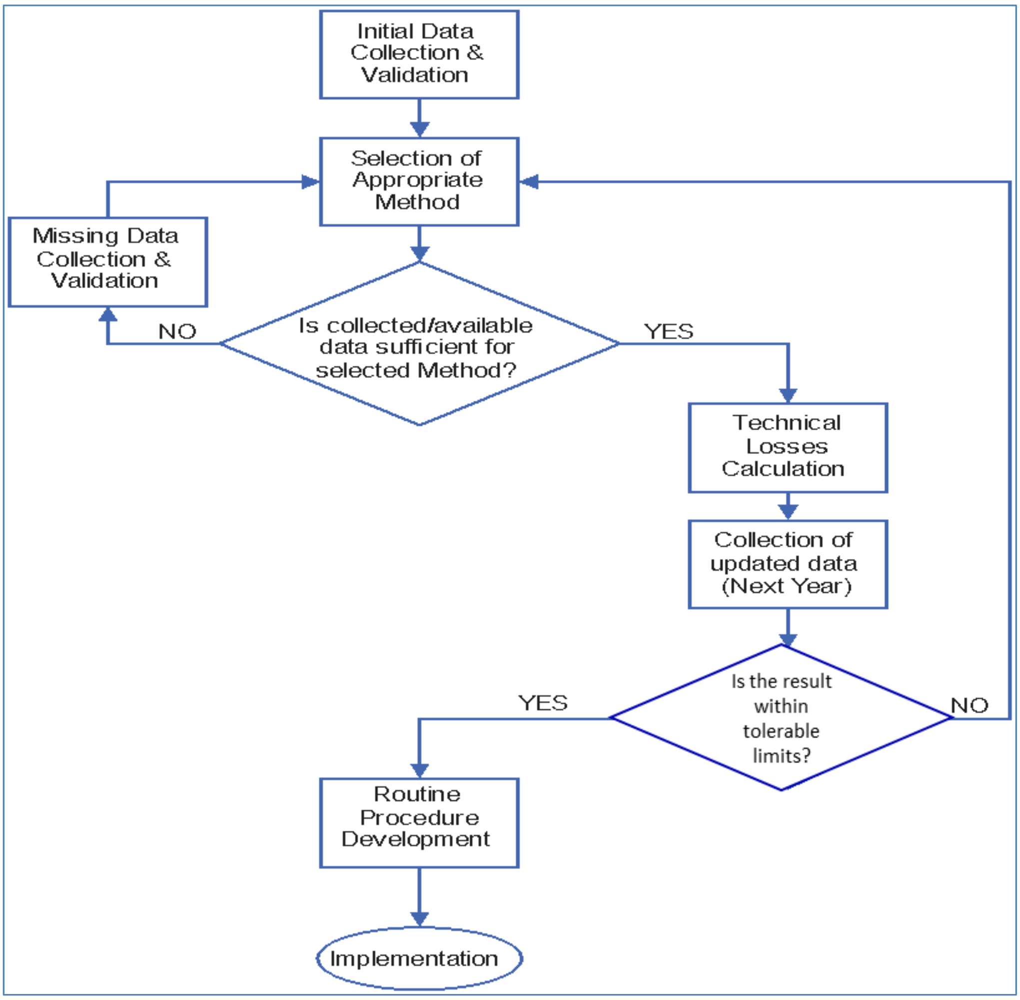


Figure 3-3: Algorithm for selection of technical loss estimation method

Provided available data, the technical loss calculation for Liberia Electricity Company within the scope of this study is based on Analytical and Estimative Methods.

3.2 DATA COLLECTION

Technical loss calculation requires a wide spectrum of accurate data on different aspects of the power system. Technical parameters of the network elements (e.g. lines, transformers, etc.), detailed network topology (single line diagrams), and nodal demand data are required for accurate system modeling and power flow studies. The quality of results is highly dependent on the quality of input data. In this respect, this study faced a great challenge, since both availability and accuracy of data in LEC are far from satisfactory. In most cases, available data needs additional processing, validation, and comparison with data from other sources.

In this case, a large portion of the initial data was sourced from studies and reports done previously for LEC by international consultants and agencies. However, much of the data was outdated and contained inconsistencies and contradictions. Because of this, considerable time was spent on collection, validation and verification of conflicting data sources. When discrepancies between reports and data obtained from the various sources occurred, the most recent source was used.

Nevertheless, due to the lack of accurate and reliable input data, some parts of this study are based on typical or standard values, sampling, best estimates, and reasonable assumptions.

3.2.1 Allocated/Nodal Demand Data

Nodal demand data or load allocation among individual distribution lines and transformers is critical for accurate power flow studies. Unfortunately, this data is currently unavailable at the LEC. While a majority of the LEC feeders and some distribution transformers are equipped with modern digital electricity meters, distribution meter data collection seems to be a major gap in the LEC. Neither interface equipment (e.g. data cables) nor appropriate software or personnel capability was available at the LEC during this study.

Hence, this study was forced to make several key assumptions regarding load allocation among individual distribution transformers and other aspects of the system.

Due to lack of appropriate metering, the data on electricity supplied to individual substations' outgoing MV feeders was collected from operator logs and is based on manual hourly records of substation kilowatt meters, ammeters, and substation control meterage.

Figure 3-4: Substation kilowatt meters and ammeters at the Bushrod substation

3.2.2 Data Completeness & Accuracy

As noted above, data collection, analysis, and storage has not been prioritized at the LEC. There are no operational procedures in place, and data is not being digitized, analyzed, or properly stored.

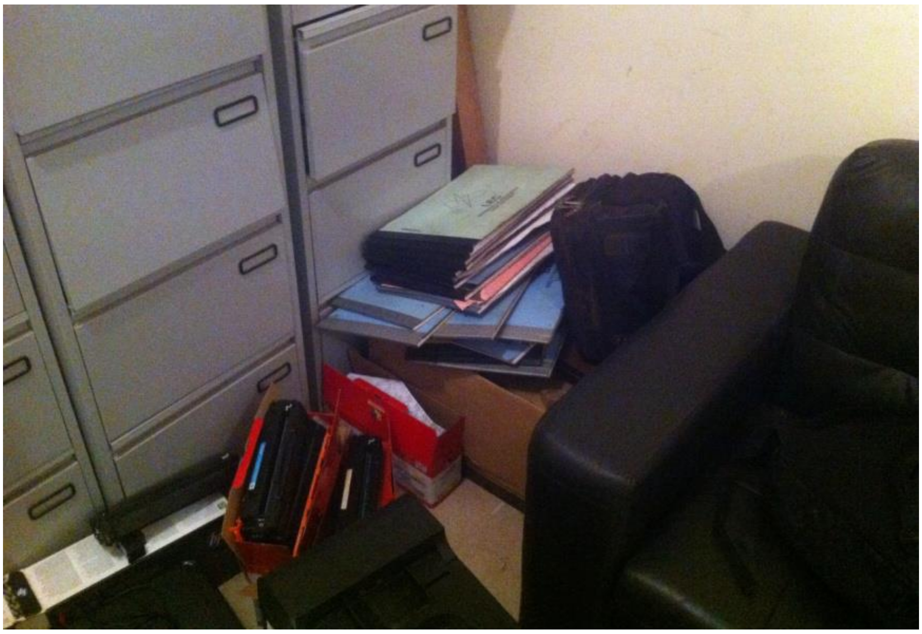


Figure 3-5: Dispatch log storage

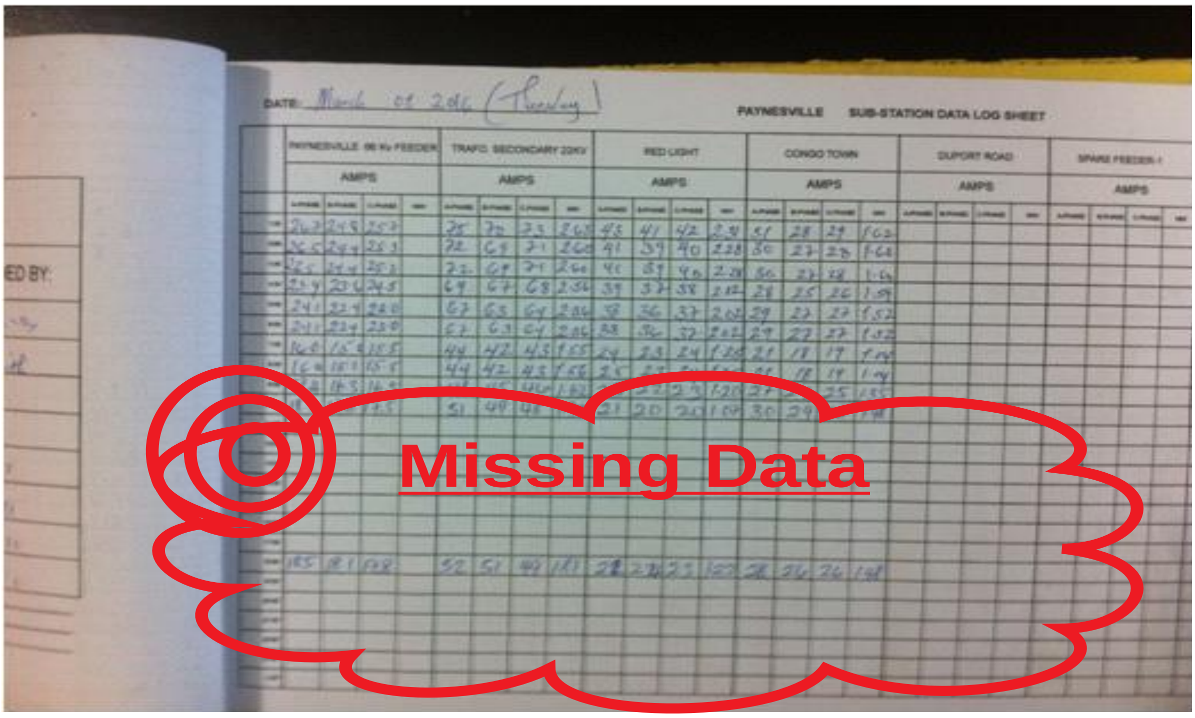


Figure 3-6: An example of missing data in dispatch logs

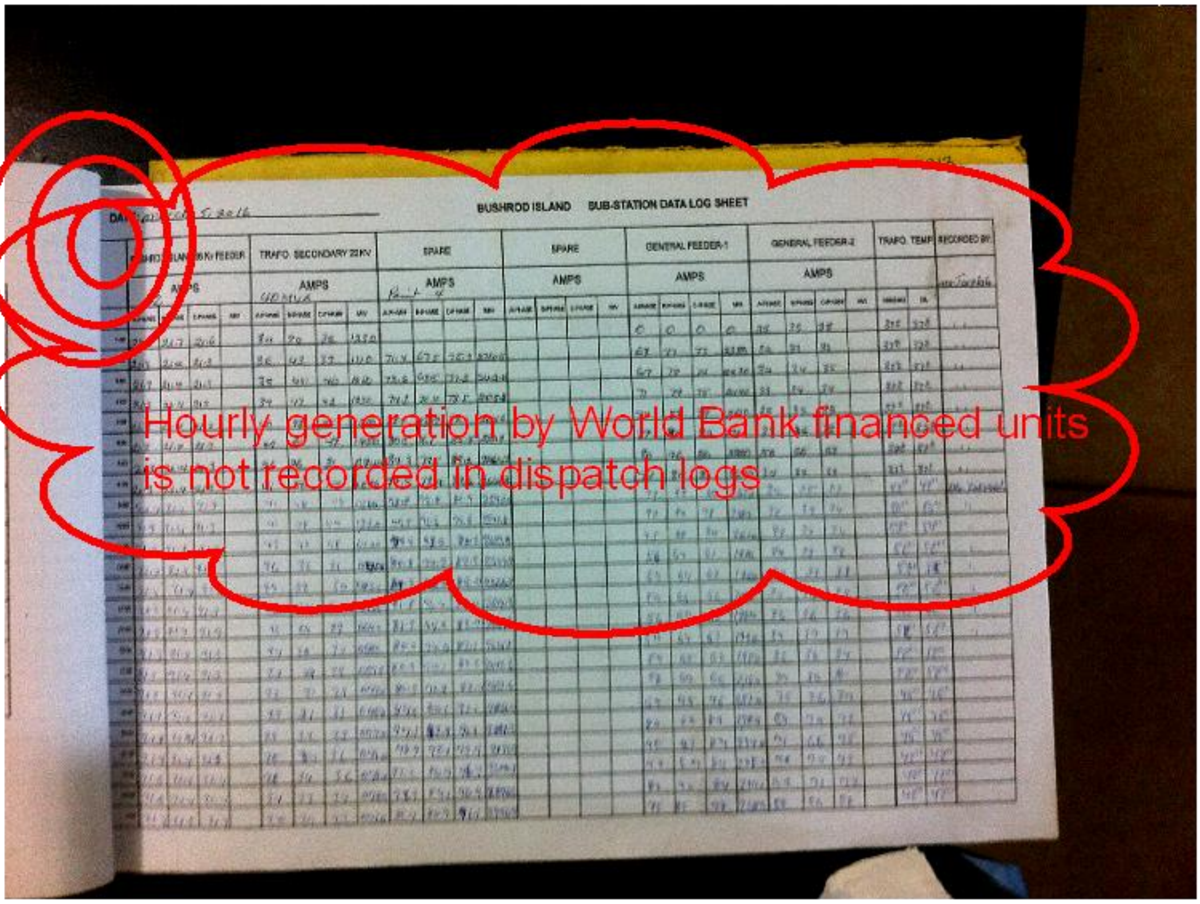


Figure 3-7: Missing data due to outdated log template

3.2.3 Existing single line diagrams and drawings

It should be noted that most of the available technical documentation, drawings and single line diagrams of the network and substations (e.g. single line diagram of Bushrod substation presented below) at the LEC are outdated. Hence, significant time was required to determine the current status and model, illustrated on the following page.

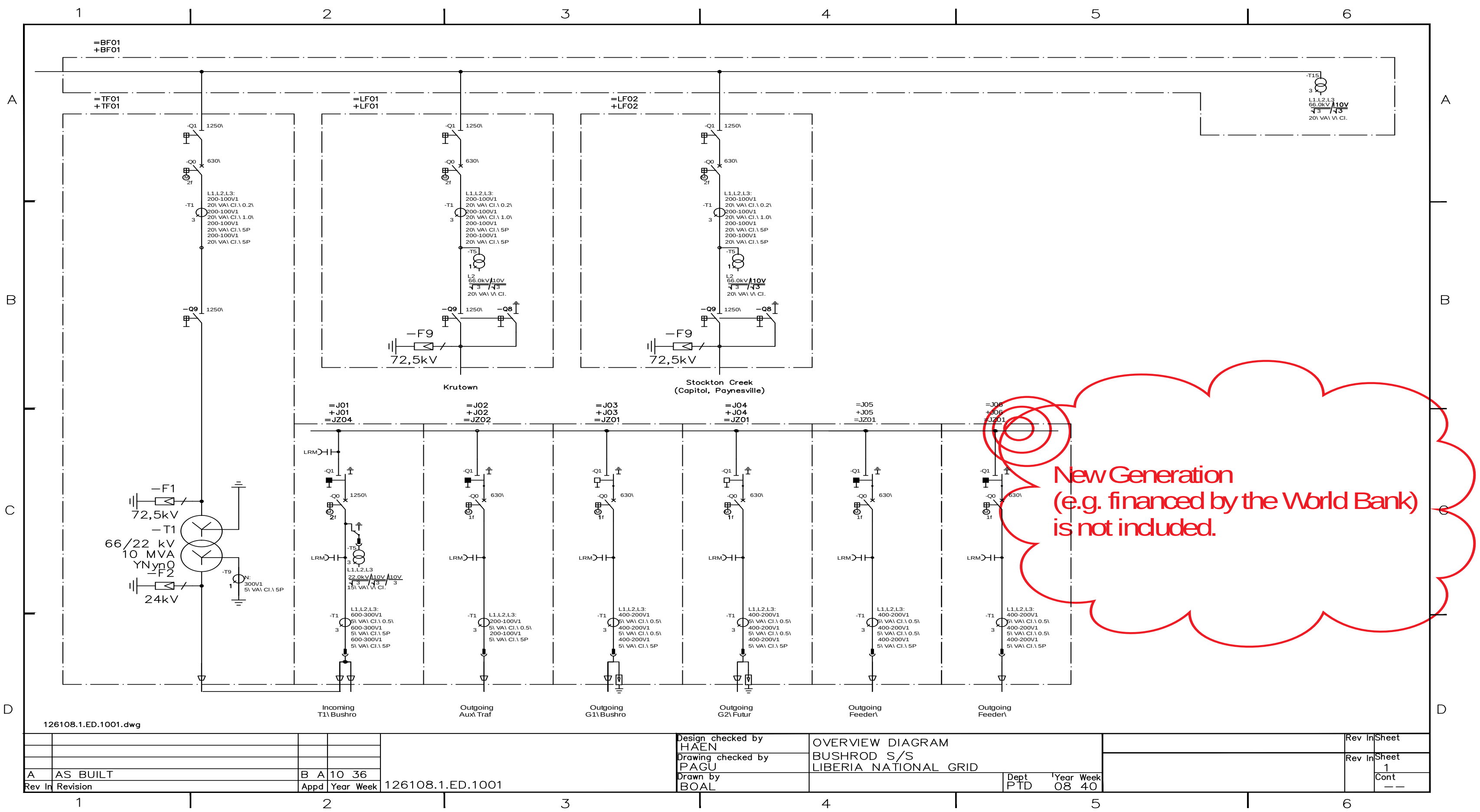


Figure 3-8: Bushrod substation diagram

Given the data limitations described above, this study considers that:

- Despite numerous issues with the accuracy and reliability of collected data, it seems to be the only data available for the purpose of technical loss estimation;
- The top-down approach will provide a reasonable level of accuracy in overall LEC transmission and distribution technical losses estimation (however, this method cannot provide accurate allocation of losses at different network nodes);
- Scaling the modeled losses to produce an overall loss would represent the best estimated overall losses and preserve the relativity of individual contributions to the overall network losses;
- Therefore, the above process for determining the technical losses should produce a fair and accurate outcome.

3.3 NO-LOAD LOSSES

The overall network no-load power losses (ΔP_{NLL}) are estimated as the sum of no-load power losses of individual substation and distribution transformers.

The associated energy no-load losses (ΔW_{NLL}) are calculated as follows:

$$\Delta W_{NLL}\ (\text{kWh}) = \Delta P_{NLL}\ (\text{kW}) \times 8760\ \text{hrs} \qquad [3]$$

The no-load power losses for individual substation and distribution transformers were obtained from available as-built documentation, manufacturer's data sheets, visual examination of transformer nameplates of both some of the currently installed transformers and transformers stored at the LEC backyard.[8] Typical, standard, and/or sample data was applied for equipment where such data was missing.

The average no-load losses were calculated for each typical size/rating of distribution transformers.

[8] Since most of the LEC distribution transformers are pole-mounted, the visual access to the nameplates is very limited.


Figure 3-9: Transformers stored at the LEC backyard in Bushrod

Based on the above data ratios of individual power, no-load losses for most typical LEC Distribution Transformers were estimated as follows:

Table 3-1: No-load losses of LEC transformers

Rated Capacity [kVA]	NLL [W]	NLL [% of transformer rated capacity]
350	769-773	0.22%
250	400-683	0.16%-0.27%
225	410	0.18%
100	205	0.21%
25	62	0.25%
15	45	0.30%

Figure 3-10: Examples of most typical LEC distribution transformer nameplates

3.4 LOAD LOSSES

In general, the load losses are calculated on the relevant part of the network under peak demand condition using specialized system modeling software and power flow studies.

The associated energy losses are calculated from power losses by application of an appropriate Load Loss Factor (LLF) as follows:

$$W_{LL}\ (kWh) = \Delta P_{LLmax}\ (kW) \times LLF \qquad [4]$$

It is worth noting that the LLF is not applied to no-load losses as they are not dependent on the transformer loading.

3.4.1 Peak Demand and Load Duration Curve

While no accurate and detailed demand data were found in LEC, the available gross generation hourly data for duration January to December 2015 was used to determine system annual load characteristics, load duration curve, and system coincidental peak values.

System hourly gross generation data was obtained from LEC and was compared and mutually complemented with the substation dispatch logs. Some minor approximation and mathematical data substitution techniques were applied to missing data cells.

It should be noted that LEC does not keep a record of auxiliary consumption by generating plants. Hence, it was assumed at 60% of rated capacities of installed auxiliary transformers or about 3% of Gross Capacity Generation based on accepted industry norms.

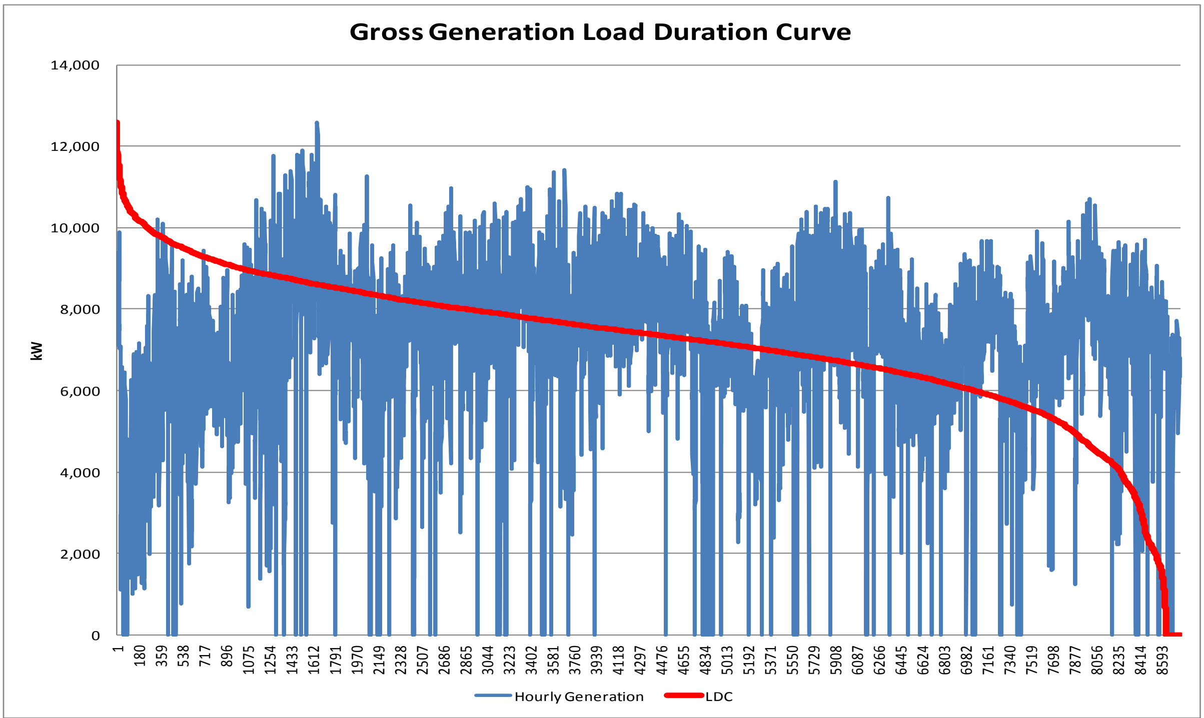


Figure 3-11: Annual (2015) Gross Generation Records and respective Load Duration Curve

Nevertheless, the data integrity was still far from sufficient. As can be noted from the hourly generation chart (blue line) there are too many cases when total system generation was either not properly recorded or was actually equal to zero (i.e. system blackout). After excluding all cases when system blackouts could be explicitly tracked from available dispatch logs, minor approximation and mathematical correlation techniques were applied to substitute missing data cells.

Analysis of the Gross Generation pattern and the resulting LDC shows that the system is running above 50% of the annual peak load at most hours during a year. As there is a lack of developed industrial consumption with multi-shift operation cycles, this is a clear indication that LEC lacks generation capacity, and thus current gross generation-demand balance is representing generation availability rather than actual demand. Moreover, LEC is still forced to implement load shedding, and thus in some cases recorded values represent suppressed gross electricity demand. Hence, at this stage most of the additional/new generation will be absorbed by the existing and prospective demand, provided connection availability and transmission adequacy, which will contribute notably to the load losses.

It should be noted that two relatively large generating plants (10MW funded by the World Bank and 18 MW funded by the GOL) units owned by the GOL were near final testing and commissioning during the last stages of this study. Thus, a certain increase to the level of future load losses could be expected.

Based on analysis of the load duration curve and annual hourly logs, it was determined that system coincidental peak usually happens in March. Parameters of generation and outgoing feeders at the annual system coincidental peak hour were defined for further power flow modeling.

According to the available data, the annual gross peak generation (Pmax) was approximately 12.6 MW, and recorded annual gross generated energy (Wa) was 63 GWh[9].

Power supplies to individual substation outgoing feeders at the moment of system coincidental peak hour were obtained from substation operator logs.

3.4.2 Load Loss Factor and Peak Equivalent Hours

Load losses vary with the square of the load. The momentary power load loss (ΔP_{LL}, in kWh) in a particular element of the network, with resistance (R) and voltage (U), can be defined as follows:

$$\Delta P_{LL} = \frac{P^2+Q^2}{U^2} * R \qquad [5]$$

Where *P* and *Q* are respective active (kW) and reactive (kVAr) power transferred by that network element.

Ideally, to calculate the energy load losses ΔW_{LL} (kWh), it would be necessary to integrate all momentary values of ΔP_{LL} *(kW)*. This is practically impossible, so a methodology to analyze load losses

[9] At many places in the report the gross generation is mentioned as 58 GWh while in this section gross generation is considered to be 63 GWh. This is due to the fact that for overall system losses estimation the period of analysis is Nov’14 to Oct’15 while for technical losses estimation the period of analysis is Jan’15 to Dec’15. In Nov’15-Dec’15 LEC started testing 10MW World Bank-funded HFO generating station which may have significant impact on electricity billing and thus needed to be excluded from overall losses assessment. In both the durations the peak load month (Mar’15) remains common and hence does not impact the technical losses assessment.

based on the energy consumed has been developed by the industry. This methodology is based on using load loss factor (τ) and system peak equivalent hours (T_{max}). According to this methodology, the energy load losses ΔW_{LL} (kWh) are calculated with the following formula:

$$\Delta W_{LL} = \Delta P_{LLmax} * \tau \qquad [6]$$

Where ΔP_{LLmax} (kW) are the momentary power losses in the network during the system peak.

T_{max} represents the fraction of the yearly time in which energy transmitted at peak load conditions is equivalent to the actual energy transmitted.

$$T_{max} = \frac{W_a}{P_{max}} \qquad [7]$$

Related load loss factor (τ) represents the fraction of yearly time of peak loss (which occurs at peak load) equivalent to actual load losses. In essence, the load loss factor is the number of hours of peak loads which will produce the same total losses as is produced by the actual loads over a specified period of time.

Different empirical models have been developed to determine the relationship:

$$\tau = f(T_{max}) \qquad [8]$$

And some examples are:

$$\frac{\tau}{8760} = \left(\frac{T_{max}}{8760}\right)^x \qquad [9]$$

$$\tau = A * \left(\frac{T_{max}}{8760}\right) + B * \left(\frac{T_{max}}{8760}\right)^2 \qquad [10]$$

with A being between 0.15 to 0.5 and the B value between 0.5 and 0.85, with additional feature of A+B=1 (but there are exclusions from the last condition).

The physical interpretation of all these formulae is hard and is not always proven[10]. However, the following two empiric formulas are being widely used for practical purposes in a number of power systems including some of European countries, Russia and others. The mathematical error between technical losses calculated in accordance with these formulas and computed based on real time data acquisition systems is mostly within a reasonable allowance (engineering tolerance).

$$\tau = 0.17T_{max} + 0.83* (T_{max}^2/t) \qquad [11]$$

$$\tau = 8760 * \left(0.124 + \frac{T_{max}}{10^4}\right)^2 \qquad [12]$$

The peak equivalent hours (T_{max}) was computed at the level of 4,976 hours. Respective LLF *(τ)* was computed in accordance with the empiric formulas [11] and [12] above and lies within the range of 3200-3400.

[10] Electrical Energy Efficiency: Technologies and Applications By Andreas Sumper, Angelo Baggini

3.4.3 Load Flow Software - ETAP®

LEC has a license for ETAP® – one of the most efficient industry standard power system simulation and analysis software tools available today. This software was used for various load flow and power loss analyses for the purpose of this study. Meanwhile, an extensive on-the-job training was provided to LEC planning engineers on system analysis using this software.

Figure 3-12: On-the-job training of LEC planning engineers

3.4.4 Modeling and Power Flow Studies

Technical load losses on system peak were determined by development of appropriate models and power flow studies using ETAP® software. Resulting energy load losses were determined using industry standard techniques for estimating energy losses based upon peak load power flows as described above in this report.

The modelling and power flow studies were conducted for various levels and subsystems to allow for disaggregated technical loss estimates for transmission and distribution networks.

3.4.5 LEC Transmission

The technical parameters of LEC transmission were mostly modeled based on as-built documentation. Transmission lines, which consist of multiple sections with different technical parameters (e.g. 66kV OHL Bushrod-Kru Town), were modeled accordingly. However, in some cases where specific technical parameters were not available neither from as built documentation or from the equipment nameplates, typical and/or standard values for similar equipment were used.

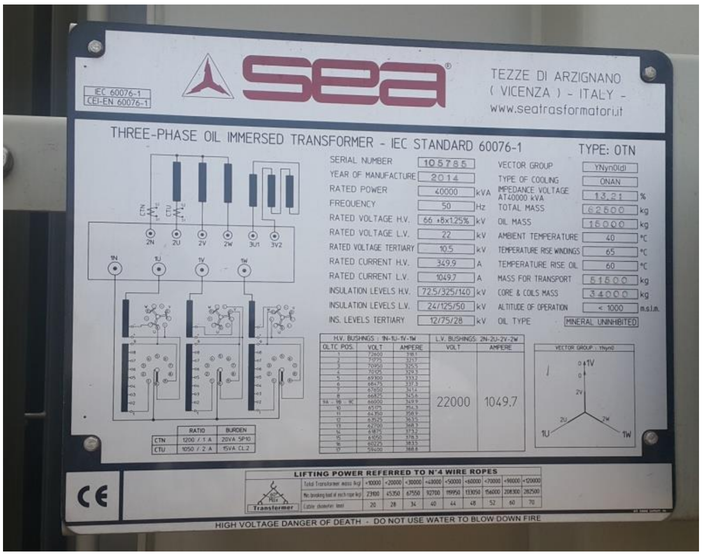


Figure 3-13: Nameplate of 40MVA Transformer at Bushrod S/S (Data on Transformer No-Load Losses and Load Losses is missing)

Initially, the individual outgoing MV feeders were modeled as lumped loads connected to the transmission substations to allow for disaggregated load loss computation of the Transmission. Later, those with available technical data sufficient for detailed modeling were added to the system model as composite/nested networks.[11]

Some of the network elements that do not have a notable impact on technical losses (such as circuit breakers, disconnectors, etc.) were omitted from the modeling due to data and time restrictions.[12]

The modeled one line diagrams of LEC system and sub-systems is provided in Appendix A

3.4.5.1 MV Feeders

Despite an extensive data collection within the scope of LEC assets GIS mapping, LEC was unable to provide a detailed topology for most MV feeders. Collecting data on all feeders in order to define a technically detailed feeder topology would require considerable time given the large amount of necessary field investigations and availability of experienced network engineers who could visually determine the capacity of installed transformers.

Hence, four (4) sample feeders with available and relatively accurate data on location and installed capacity of distribution transformers were selected as samples for the purpose of this study. Technical parameters were modelled based on as-built documentation, data obtained from LEC Planning and Network Departments. Results of GIS mapping were utilized for determining the topology of the feeders (length of individual sections, coordinates and exact location of distribution transformers, etc.).

[11] The composite network feature of ETAP® allows modeling parts or subsystems as an aggregation of all components in a subsystem and place anywhere on a one-line diagram or within other composite network. The nested composite networks are also part of the overall system and further study runs include all the elements and connections nested within the composite networks. This allows modeling systems and nesting them by their order of importance, by study requirements, by logical layouts, etc.

[12] These elements can be added to the existing system model later for the purpose of short circuit, relay protection and other engineering studies which are beyond the scope of this project.

It was agreed that provided with the training delivered during this study, the LEC Planning Department will continue data collection and further detailed modelling of all MV feeders up to their detailed as-built status in the future.

3.4.5.2 22kV Two-Wire/Single Phase Feeders

LEC has an extensive 22kV network with connected 22/0.23 kV single phase transformers. Modelling all these feeders within the scope of this study was unachievable due to lack of detailed data and time limits. Hence, one of the most complicated feeders of such type was selected as a sample to evaluate the range of technical losses.

3.4.5.3 LV Network

The electricity consumption by individual LV end-users of LEC is low, while in general the LV feeders are relatively short.[13] Hence, the losses in LV network will not contribute much to the total technical losses.

However, there is no sufficient data available at the LEC for LV network modelling. Neither detailed technical parameters nor network topology of LV lines are currently available at the LEC.

Lack of comprehensive data and complexity of LV network modeling are common issues for most electric utilities in developing countries. Hence, utilities are forced to use various approximation approaches for technical losses estimation in LV network.

Some utilities exclude the LV (0.4/0.23 kV) distribution network from the modeling both due to lack of data and for model simplicity, but up to 25% of total computed technical losses allowance is made for the part of the network, which is not modeled explicitly.[14] This method was also selected for the purpose of this study.

The modeled MV and LV network is provided in Section 8.2.

[13] According to the LEC Planning less than 500 meters

[14] Transmission and Distribution Electrical Engineering By Colin Bayliss, Brian Hardy

3.5 SUMMARY OF RESULTS

3.5.1 Main System Parameters

Main system parameters used for the purpose of this study are primarily based on gross generation dispatch logs for 2015 (Jan-Dec 2015), shown below in Table 3-2.

Table 3-2: Main system parameters used for technical loss estimation

Parameter	Symbol (Unit of Measurement)	Value
Annual Gross Energy Generation	W (kWh)	62,685,374
Annual Gross Peak Generation	P_{max} (kW)	12,600
System peak equivalent hours	T_{max} (hrs)	4,976
Load Loss Factor	τ_1	3,200

3.5.2 Auxiliary Consumption by Generating Plants

As mentioned in the previous section, LEC does not keep a record of auxiliary consumption by generating plants. Hence, based on international practices, the auxiliary power demand by generating plants during the peak hour was assumed at the level of 60% from the rated capacities of installed auxiliary transformers, or about 3% of Gross Capacity Generation. The values of auxiliary consumption by generating plants is shown in Table 3-3.

Table 3-3: Auxiliary consumption by generating plants

Parameter	Value
Annual Peak Generation Gross P_{Gmax} (kW)	12,600
Auxiliary Consumption ΔP_{ACG}(kW) at 3% of Gross Capacity	378
Auxiliary Energy Consumption ΔW_{ACG} (kWh)	3,311,280
Auxiliary Energy Consumption as % of Gross Energy Generation	**5.3%**

The auxiliary consumption by generating plants is calculated as:

ΔW_{ACG} (kWh) = ΔP_{ACG} (kW) x 8760 (hrs) =378*8760 = 3,311,280 (kWh)

3.5.3 No-Load Losses in Transmission and Generation Transformers

Since no data was found on no-load losses in LEC transmission and generation transformers, data for similar transformers from publicly available manufacturers' datasheets was used.

It should be noted that no-load losses in generation transformers may vary during the year depending on the number and dispatch of existing generation units (i.e. number of energized transformers). However, due to lack of detailed data, for the purpose of this study it was assumed to be constant and equal to no-load losses in generation transformers during the annual peak hour. The calculations for the no-load loss in generation transformers is shown in Table 3-4.

Table 3-4: No-load losses in LEC generation transformers

LEC Generation Transformers			
Substation	**Energized**	**Rated Capacity (kVA)**	**ΔP_{GNLL} (kW)**
Bushrod	1	14000	14.1
	4	1600	10.4
Congo Town	2	1600	5.2
Kru Town	3	1600	7.8
No-load loss (capacity) in generation transformers ΔP_{GNLL} (kW)			37.5
No-load loss (energy) in generation transformers ΔW_{GNLL} (kWh)			328,500
No-load loss (energy) in generation transformers as % of Gross Energy Generation			**0.5%**

The no-load energy losses in generation transformers is estimated as follows:

ΔW_{GNLL} (kWh) = ΔP_{GNLL} (kW) x 8760 (hrs) = 37.5*8760 = 328,500 (kWh).

The no-load losses in LEC transmission transformers is shown in Table 3-5.

Table 3-5: No-load losses in LEC transmission transformers

LEC Transmission Transformers			
Substation	**Energized**	**Rated Capacity (kVA)**	**ΔP_{TNLL} (kW)**
Bushrod	1	40,000	40.4
Capitol	1	10,000	10.6
Kru Town	1	10,000	10.6
Pennsville	1	10,000	10.6
No-load losses (capacity) in LEC transmission ΔP_{TNLL} (kW)			72.26
No-load losses (energy) in LEC transmission ΔW_{TNLL} (kWh)			632,998
No-load loss (energy) in transmission transformers as % of Gross Energy Generation			**1%**

The total annual no-load energy losses in transmission transformers are estimated by formula shown below:

ΔW_{TNLL} (kWh) = ΔP_{TNLL} (kW) x 8760 (hrs) = 72.26*8760 = 632,998 (kWh)

3.5.4 No-load Losses in LEC Distribution Transformers

No-load energy losses for LEC distribution transformers are computed according to the methodology described in section 3.3. The no-load losses in LEC distribution transformers is shown in Table 3-6.

Table 3-6: No-load losses in LEC distribution transformers

		Three phase transformers		Single phase transformers	
Substation	**Feeder**	**Transformer Capacity (kVA)**	**ΔP_{NLL} (kW)**	**Transformer Capacity (kVA)**	**ΔP_{NLL} (kW)**
Bushrod Island	Point Four	1,300	2.96	9,410	28.27
	Port	2,050	6.10	8,090	24.55
Capitol	Congo Town	11,900	27.99		
	Kru Town	3,400	8.36	270	*0.81*
Kru Town	Mamba Point	2,590	6.23	2,010	*6.03*
	Water & City	5,510	11.54		
Pennsville	Congo Town	3,300	8.43	45	0.14
	Red Light	4,000	11.59		
Total		34,050	83.19	19,825	59.79
Total No-load Losses (capacity) in distribution ΔP_{NLL} (kW)					143
Total No-load Losses (energy) in distribution ΔW_{NLL} (kWh)					1,252,592
No-load loss (energy) in distribution as % of Gross Energy Generation					**2%**

The total annual no-load energy losses in distribution transformers is calculated as follows:

ΔW_{DNLL} (kWh) = ΔP_{DNLL} (kW) x 8760 (hrs) = 143*8760 = 1,252,592 (kWh)

3.5.5 Load Losses in LEC network

3.5.6

Table 3-7 presents the capacity load losses in LEC's high voltage (HV), medium voltage (MV) and low voltage (LV) network based on the modelling of the network ETAP® and power flow analysis at peak load conditions.

Table 3-7: Load losses in LEC network

Load Losses (ΔP_{max})	%	ΔP_{LLmax} (kW)	Remarks/value
Load Losses in HV Network	1.9%	227	Modeled "as-built"
Load Losses in Three Phase MV Feeders	2.0%	257	Based on four sample feeders modeling; Allocation of individual transformer loading - proportional to their rated capacity; Loading among phases – symmetrical[15]
Load Losses in Single Phase MV Feeders	2.8%		Based on a model of a sample feeder; Allocation of individual transformer loading - proportional to their rated capacity;
Load Losses in LV (0.4/0.23) kV lines	1.0%	121	25% allowance of the explicitly modeled losses
Total (capacity) load losses at peak load ΔP_{LLmax} (kW)			605
Total (energy) load losses at peak load ΔW_{LLmax} (kWh)			1,935,309

[15] An asymmetry among loading of phases will impact the load losses. However, this assumption was made given the lack of actual metering data and the fact that the average impact of asymmetry will not critically change the overall picture.

Load Losses (ΔP_{max})	%	ΔP_{LLmax} (kW)	Remarks/value
Load loss (energy) in LEC network as % of Gross Energy Generation			**3.1%**

The load losses are calculated with the formula below:

$W_{LLmax} = \Delta P_{LLmax} \times \tau$ (kWh) = 605*3200=1,935,309 where τ is equal to 3200 as discussed in section 3.4.2

3.5.7 Summary of Power Balance at Peak Load

Based on the calculations and estimates outlined in previous sub-sections, Table 3-8 provides a summary of power capacity balance in the LEC network. As seen in the table, during peak hours, approximately 1.2 MW (roughly 9.8% of peak generation) is lost in the network before the electricity reaches the customer.

Table 3-8: Summary of Power Balance at Peak Load

Network Node	Load (kW)
Annual Peak Generation Gross P_{Gmax} (kW)	12,600
Auxiliary Consumption ΔP_{ACG}(kW)	378
Net Generation P_{GNet} (kW)	12,222
No-load Losses in Generation Transformers ΔP_{GNLL} (kW)	38
Net output to HV Network P_{HV} (kW)	12,185
Load Losses in HV Network[16] ΔP_{HVmax} (kW)	227
No-load Losses in HV Transformers ΔP_{TNLL} (kW)	72
Net input to MV Network P_{MV} (kW)	11,886
Load Losses in MV Network ΔP_{MVmax} (kW)	257
No-load Losses in MV Transformers ΔP_{DNLL} (kW)	143
Net input to LV Network P_{LV} (kW)	11,485
Load Losses in LV Network ΔP_{LVmax} (kW)	121
Net Load available to customers (kW)	11,364
Total Power Capacity Load Losses ΔP_{LL} (kW)	***605***
Total Power Capacity No-load Losses ΔP_{NLL} (kW)	***253***
Grand Total Power Capacity Losses ΔP_{max} (kW)	**1,236**

[16] Including Load Losses in Generation Transformers

3.5.8 Summary of Technical Energy Losses

Based on the calculations and estimates in the previous sub-sections, the table below summarizes technical energy losses in the LEC network:

Table 3-9: Summary of technical energy losses

Network node	Energy loss (%)
Losses in Generation	**5.8%**
Auxiliary Energy Consumption in LEC generators	5.3%
No-load losses in generating transformers	0.5%
Losses in HV network	**2.2%**
No-load losses in HV network	1.0%
Load losses in HV network	1.2%
Losses in MV network	**3.3%**
No-load losses in MV network	2.0%
Load losses in MV network	1.3%
Losses in LV network	**0.62%**
Load losses in LV network	0.62%
Total technical energy losses in LEC network	**11.92%**
Auxiliary Energy Consumption in LEC generators	5.3%
Total Energy No-load Losses	3.52%
Total Energy Load Losses	3.1%

3.6 CONCLUSIONS AND RECOMMENDATIONS

- PATRP used a conservative approach to estimate the technical energy losses given limited availability and reliability of data.
- Technical losses are not a major component of the total electricity losses in the LEC network. Provided the fact that most of the network facilities are brand new or relatively new, fairly designed, and sometimes even overrated, the current technical losses of electricity are within the expected range.
- Meanwhile, the lack of detailed technical and operational data prevents accurate technical loss allocation among customers. Thus, planning specific projects to reduce technical losses is complicated.
- Better understanding of allocated sources and reduction of technical losses will be possible after implementation of proper operational practices and procedures.
- Data collection, exchange, analysis and storage practices at LEC require significant improvement.
- Improvement of commercial metering and implementation of routine system electricity balance computations is required.
- Proper electricity metering, as well as metering of other key parameters such as nodal voltages, would improve both system planning and operations.

- Estimated technical losses are reflecting the current system status and demand. The situation with the electricity technical losses may change drastically as more new customers are gaining access and being connected to the network rapidly. Planning of new connections is mostly spontaneous, reactive, based on immediate requests and availability of funds as well as closest available connection points, and hence lacks proactive system analysis and system planning.
- During this study, a number of significant issues were noted regarding system reliability and security, outdated relay protection coordination, etc. While these issues are beyond the scope of this study and fixing these issues will require a significant effort, they were brought to the attention of LEC, including:
    - Current system design criteria and transmission network topology do not provide for security and reliability of the system;
    - Disconnection of a single 40MVA transformer installed at the Bushrod S/S or associated busbar will lead to system blackout as it does not meet basic N-1 criteria;
    - System protection and protection coordination studies are outdated and LEC still needs to develop in-house capacity to perform these routine studies.

4. SEGREGATION OF TECHNICAL AND NON-TECHNICAL LOSSES

4.1 INTRODUCTION

The purpose of this task was to obtain generation output and sales data from LEC in order to estimate overall system losses and non-technical losses by excluding technical losses from the overall losses. Further, the non-technical losses are segregated into various sources responsible for losses. This task also includes results of field visits conducted to assess security of installations, installation practices, and functionality of customer meters.

4.2 ESTIMATE OF OVERALL AGGREGATE TECHNICAL AND COMMERCIAL (AT&C) LOSSES

4.2.1 Generation and peak demand

At present, customers in Monrovia are supplied from HSD plants in Congo Town, Kru Town and Bushrod generating stations. The World Bank-funded 10 MW plant initiated operations in February 2016 and is excluded from analysis. Table 4-1 below provides fuel supply, consumption, plant efficiency and electricity generation from LEC generating plants for the one-year period of November 2014 to October 2015. A one-year rolling period is considered to account for seasonal variations while system losses are calculated.

Table 4-1: Generation data from LEC power plants

Generation Plant		Nov-14	Dec-14	Jan-15	Feb-15	Mar-15	Apr-15	May-15	Jun-15	Jul-15	Aug-15	Sep-15	Oct-15
Congo Town	Fuel Consumed (kGal)	38	18	34	45	25	43	51	57	60	59	56	60
	Fuel Supplied (kGal)	39	10	41	44	27	41	52	55	57	64	60	78
	Plant Efficiency (kWh/Gal)	14.4	15.6	13.9	14.5	14.7	14.8	15.1	14.8	14.9	15.1	13.5	13.3
	Generation (MWh)	550	277	475	656	369	632	771	837	893	891	754	795
Kru Town	Fuel Consumed (kGal)	55	52	49	73	101	76	76	91	65	60	103	60
	Fuel Supplied (kGal)	55	44	70	62	115	79	65	94	50	80	97	78
	Plant Efficiency (kWh/Gal)	12.8	12.9	13.3	13.5	13.3	12.2	12.0	12.9	12.8	12.0	11.8	11.4
	Generation (MWh)	707	674	648	986	1347	919	903	1170	832	718	1210	682
Bushrod	Fuel Consumed (kGal)	193	187	257	238	331	296	326	283	285	244	262	272
	Fuel Supplied (kGal)	211	189	256	237	347	313	311	307	252	295	255	290
	Plant Efficiency (kWh/Gal)	12.3	12.8	12.1	12.0	12.8	12.5	12.6	12.5	12.6	12.6	12.7	12.5
	Generation (MWh)	2369	2390	3104	2866	4234	3689	4113	3527	3592	3074	3318	3407
Total	**Fuel Consumed (kGal)**	**286**	**257**	**340**	**356**	**457**	**414**	**453**	**430**	**409**	**363**	**420**	**391**

Generation Plant		Nov-14	Dec-14	Jan-15	Feb-15	Mar-15	Apr-15	May-15	Jun-15	Jul-15	Aug-15	Sep-15	Oct-15
	Fuel Supplied (kGal)	**305**	**244**	**367**	**343**	**489**	**433**	**429**	**456**	**359**	**438**	**412**	**447**
	Plant Efficiency (kWh/Gal)	**12.7**	**13.0**	**12.4**	**12.7**	**13.0**	**12.7**	**12.8**	**12.9**	**13.0**	**12.9**	**12.6**	**12.5**
	Generation (MWh)	**3625**	**3340**	**4226**	**4509**	**5950**	**5240**	**5787**	**5534**	**5317**	**4683**	**5282**	**4883**

It is worthwhile to note that the Congo Town generating plant is the most efficient, followed by Kru Town and Bushrod. This is due to the fact that the Congo Town generating station is used as a baseload generating station while variability in customer demand is catered to some extent by Kru Town and Bushrod.

The graph in Figure 4-1 shows the peak demand in MW (which actually in this case is peak generation as there is no control center to measure customer demand) and generation during the one-year period under consideration. As the graph illustrates, March is the peak month, with demand of 12.6 MW, followed by May and June with an 11.4 MW peak. October and November see the least demand, with 9.7 MW load.

The graph also shows that peak generation (in MW) or the peak demand curve does not always follow the generation (MWh) pattern. This happens because the hourly load in MW across all the generating stations is added to get the peak load, which is actually not the coincidental peak but is usually higher than the actual coincidental peak. However, given that there is no other mechanism available at present, the aggregate of MW generation at the peak hour is a good representation of system load.

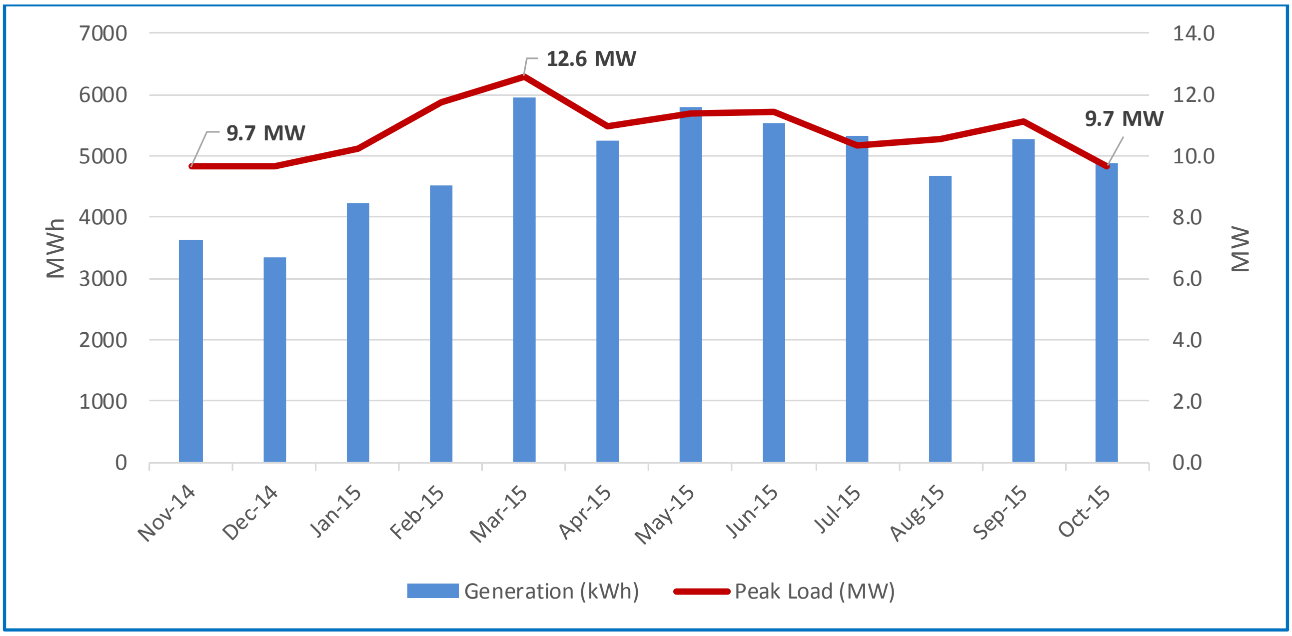


Figure 4-1: Peak Load in MW

4.2.2 Customer sales and collection

As of October 2015, LEC had 36,748 customers comprising 89.7% residential and 9.7% commercial, with the remainder of consumers consisting of the Government of Liberia, NGOs, Public Corporations, the LEC itself, and Tax Exempt customers.

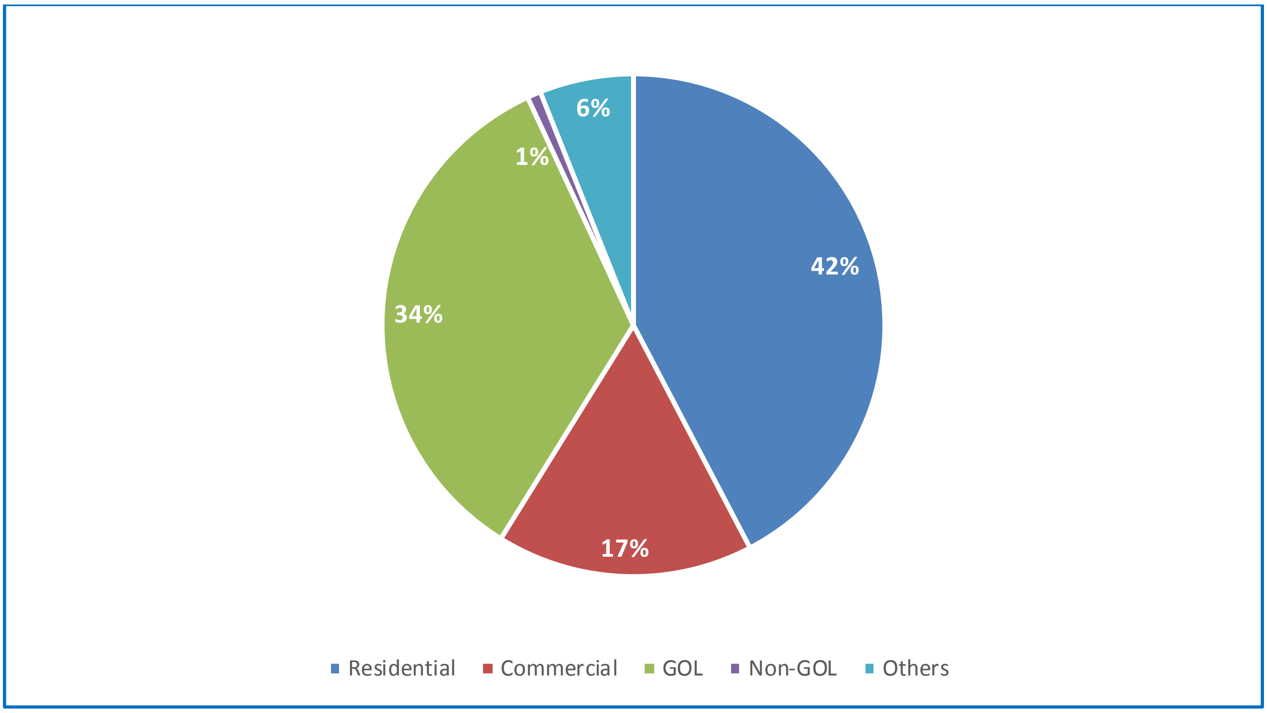


Figure 4-2: LEC Customer sales profile

Figure 4-2 provides the sales profile of LEC customers. Residential customers contribute 42% of sales to LEC, followed by GOL (34%), Commercial (17%), Non-GOL (1%) and others (6%). Thus, residential customers, which comprise almost 90% of the customer base, contribute only 42% of the revenue, while the very small number of GOL connections account for over 34% of revenue. The commercial connections, which account to only 10% of the total, contribute 17% to the sales.

Of the total customer base, 90% are pre-payment customers that contribute roughly 60% to sales, while the remaining 10% are post-paid customers and contribute 40% of the sales.

Customers in the Monrovia are served by five substations: Bushrod Island, Capitol, Congo Town, Kru Town and Paynesville. The distribution of customers and sales is represented in Table 4-2.

Table 4-2: Customer and sales distribution by substations

Substation	Customer share	Sales share
Bushrod Island	42%	15%
Capitol	8%	3%
Congo Town	18%	34%
Kru Town	20%	34%
Paynesville	12%	14%

As shown in the table, Bushrod Island serves 42% customers but contributes only 15% to the LEC revenue. This anomaly can be explained by the high concentration of low-income community connections, though the area also has a good number of residential and commercial customers.

Table 4-3 provides summary of monthly billing and collections of LEC for the one-year rolling period of November 2014 to October 2015.

Table 4-3: Monthly billing and collections from Nov'14 to Oct'15

Months	Number of Customers	Energy available for sale (kWh)	Billing (kWh)	Per Cust. Ave Consumption (kWh)	Total Billing (USD)	Collection (USD)
Nov-14	29,808	3,625,176	2,368,778	79	1,235,010	1,800,417
Dec-14	29,981	3,340,277	2,367,316	79	1,232,443	2,030,757
Jan-15	30,485	4,225,793	2,821,677	93	1,478,607	1,126,465
Feb-15	31,015	4,508,753	3,048,949	98	1,601,582	1,183,409
Mar-15	31,803	5,950,015	3,501,266	110	1,845,128	2,227,467
Apr-15	32,646	5,240,009	3,407,096	104	1,789,036	1,508,913
May-15	33,431	5,786,589	4,046,590	121	2,131,337	1,793,481
Jun-15	34,231	5,534,406	3,579,098	105	1,885,641	1,520,118
Jul-15	35,597	5,316,779	3,550,749	100	1,844,057	2,778,846
Aug-15	36,211	4,682,621	3,584,519	99	1,915,765	2,193,523
Sep-15	36,500	5,282,243	4,032,537	110	2,121,340	2,409,750
Oct-15	36,748	4,883,199	3,599,004	98	1,876,566	3,316,018
Total	**-**	**58,375,860**	**39,907,581**	**100**	**20,956,512**	**23,889,163**

The above table shows that monthly sales vary by US$ 1.2 million during low-demand periods to US$ 2.1 million during the high-demand periods.

4.2.3 Calculation of overall AT&C losses

Aggregate Technical and Commercial (AT&C) losses are calculated first by determining billing efficiency and collection efficiency in the system. Billing efficiency is defined as the ratio of the electricity billed (kWh) to customers to the electricity input (kWh) to the system. Collection efficiency is defined as ratio of the USD amount collected from the customers to the USD amount billed. The formulae for calculation of billing, collection efficiencies and AT&C loss are provided below:

$$Billing\ Efficiency\ (\eta B) = \frac{kWh\ billied\ to\ customers}{kWh\ generated\ or\ kWh\ input\ to\ system} \times 100$$

$$Collection\ Efficiency\ (\eta C) = \frac{USD\ collected\ or\ realized\ from\ customers}{USD\ billed\ to\ customers} \times 100$$

$$Aggregate\ Technical\ and\ Commercial\ Loss\ (AT\&C) = 1 - \eta B \times \eta C$$

Based on the generation data in Table 4-1 and customer sales and collection data in Table 4-3, the Figure 4-3 below shows the monthly billing efficiencies, collection efficiencies, and AT&C losses.

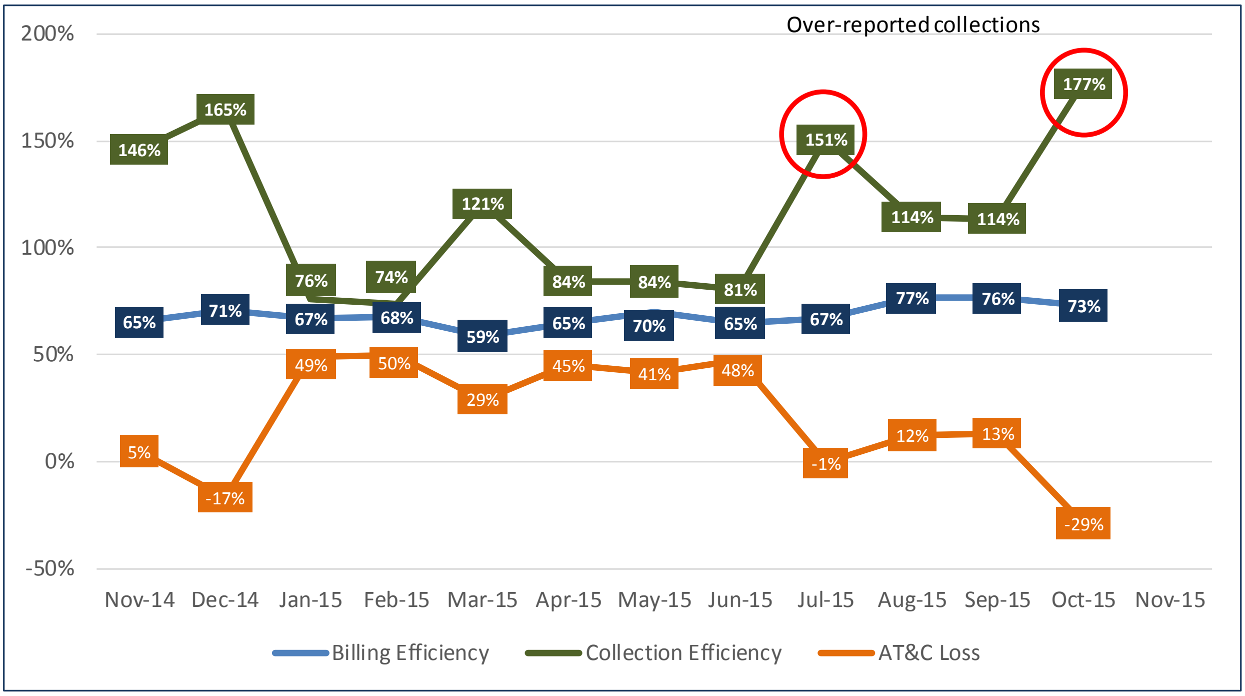


Figure 4-3 : Monthly AT&C losses for the one-year period of Nov'14 to Oct'15

During review of the monthly sales and collection details, it was discovered that payments from GOL are irregular, but when they pay the collection efficiency rises sharply as seen in some months in the graphs above. However, in two months (July 2015 and October 2015), the collection efficiency was 151% and 177%, respectively, even in absence of large GOL payments. Further, investigation revealed that in these months Liberian dollars were posted as US dollars, an error that was not detected during audit and reconciliation processes. In July 2015, a US$ 2 million pre-payment collection was posted against pre-payment sales of US$ 1.2 million. Similarly, in October 2015 a US$ 3 million pre-payment collection was posted against pre-payment sales of US$ 1 million. This resulted in over-reporting of pre-payment collection to the tune of US$ 2.8 million, which if adjusted increases the AT&C losses to over 32% for the period November 2014 to Oct 2015.

Based on the data provided by LEC for previous years, the table below shows billing efficiency, collection efficiency, and AT&C losses from 2012 to 2015.

Table 4-4: AT&C losses from 2012 to 2015

Parameters	2015 (Nov'14-Oct'15)	FY 2014	FY 2013	FY 2012
Billing Efficiency	68%	75%	71%	77%
Collection Efficiency	100%	94%	107%	82%
AT&C Losses	**32%**	**30%**	**24%**	**37%**
Revenue (millions of $)	$ 21.01	$ 19.6	$ 20.9	$ 16.3

From

Table 4-4 it is clear that the billing efficiency (the ratio of electricity generated to electricity sold to customers) has decreased from 77% in 2012 to 68% in 2015. In some months during the November 2014 to October 2015 period, the billing efficiency shows improvement, but for the duration it remains around 68%. Based on international benchmarks, this level of billing efficiency is low and is a real concern for LEC, as lower billing efficiency indicates higher losses due to theft and unaccounted sales. Best performing utilities usually have above ninety percent billing efficiency.

LEC has not implemented an energy audit or energy balance system, though it seems that the process was started at one point in 2009 or 2010. During site visits, the PATRP team found that energy meters were installed at each generating unit and at large transformers, as shown in Table 4-5 below. However, the meters are now mostly non-functional due to poor upkeep. No effort has been made by LEC in recent years to maintain or read these energy meters to ascertain electricity balance. LEC leadership was not aware that these meters had been installed.

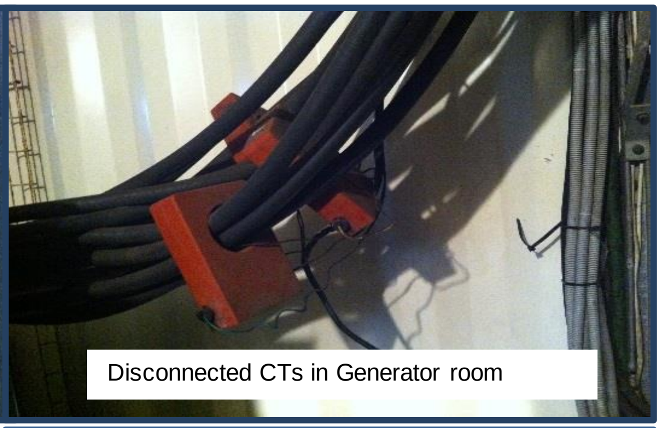
PATRP, working with LEC Commercial and IT teams, found out that at least ninety (90) large distribution transformers have energy meters as detailed in

Table 4-5. Later, the Commercial Technical team tested these meters and confirmed that most of these meters are working, though the installations will need significant upkeep and maintenance. Nevertheless, these installations can be used to start an energy balance exercise. The PATRP team guided the LEC Commercial team towards implementing procedures for conducting energy balance tests on these distribution transformers.

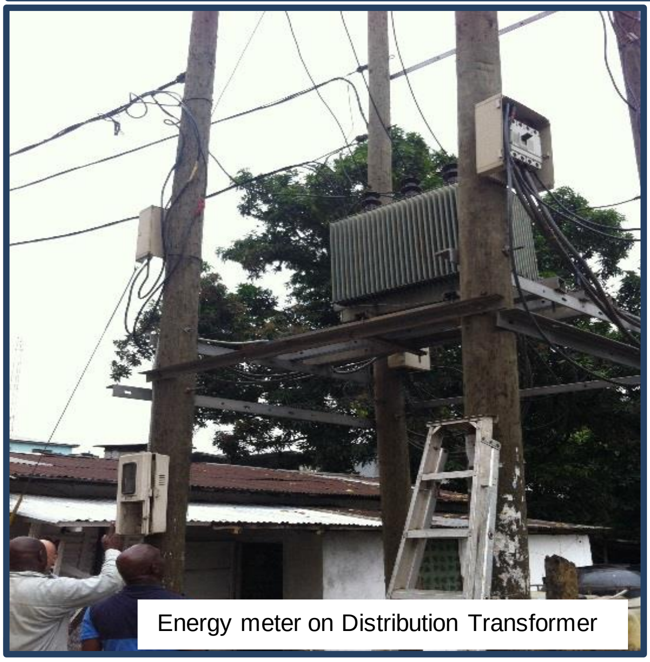
Table 4-5: Distribution transformers with energy meters

Substations	No. of Transformers
Bushrod Island Substation	**23**
St. Paul Bridge Feeder	4
Vai Town Feeder	19
Congo Town Substation	**31**
Catholic Hospital Feeder	11
Congo Town Plant	1
J F K Feeder	**19**
Kru Town Substation	20
Mamba Point Feeder	15
Water & City Feeder	**5**
Paynesville Substation	**16**
Redlight Feeder	16
Grand Total	**90**

Energy meter in Generator



Disconnected CTs in Generator room



Energy meter on Distribution Transformer

Distribution Transformer in non-functional condition

In absence of an energy balance system and lack of energy meters at incoming and outgoing feeders in substations, it is not possible to estimate non-technical losses at substation, feeder, or regional levels.

4.3 ANALYSIS OF NON-TECHNICAL LOSSES

The overall system losses (AT&C losses) are estimated to be around 32%. The total system technical losses as estimated in the previous section are around 11.92%. Thus, the total system non-technical losses are 20.08%. The table below shows the calculations:

Table 4-6: Estimation of non-technical losses

Description	Losses
Overall System Loss (AT&C)	32%
System technical Loss	11.92%
System non-technical losses	20.08%

System non-technical losses can be attributed to various sources of non-technical losses, such as faulty meters and/or theft (direct theft, meter bypass, free power etc.).

PATRP obtained data from LEC related to faulty meters replaced in 2014 and 2015. The faulty meter statistics are represented in the graph below.

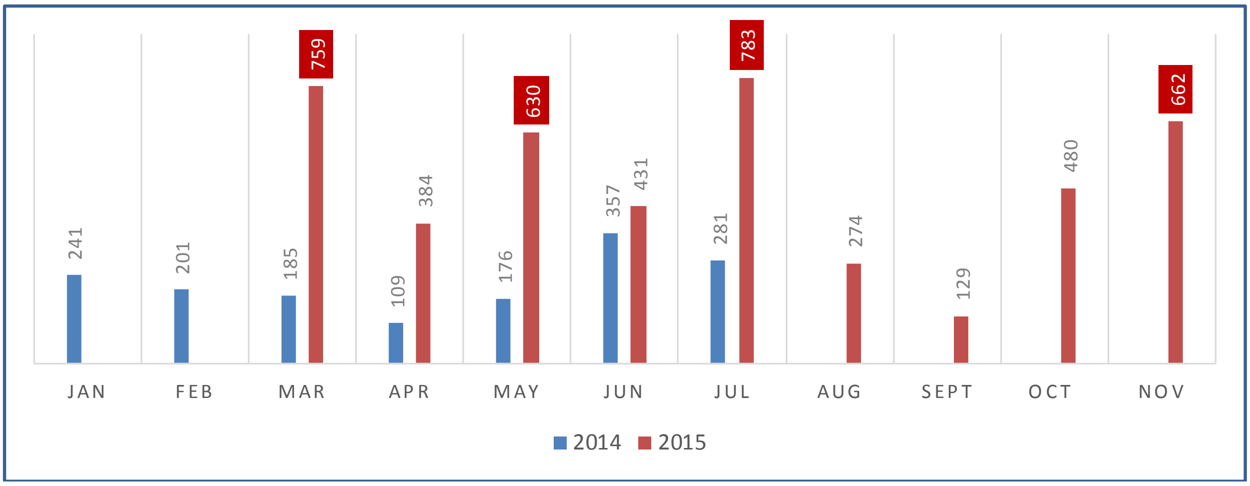


Figure 4-5: Faulty meter statistics

August 2014 to May 2015 coincided with the most recent Ebola outbreak, therefore limited data on faulty meter replacements is available for this period. From January to July 2014, a total of 1,550 faulty meters were replaced. From March to November 2015, a total of 3,966 faulty meters were replaced. Given that LEC has around 36,748 connections, such a rate is very high. The table below provides a summary of faulty meters replacement and comparisons with new connections installed during the same time.

Meter Statistics March 2015 to November 2015	
New connections	9,495
Faulty meters	4,532
Tampered Meters	715
Free Power Meters	651
Meters replaced as % of new connections	**62%**
Meters replaced as % of total connections population	**16%**

Here, faulty meters are defined as meters found to be burnt, damaged, or non-working, and thus no supply is available to customers. Usually, faulty meters replaced within one to two days of reporting do not cause noticeable impact on utility's revenues. However, at LEC, replacement of faulty meters takes weeks, and in some cases even months, and hence causes significant loss, Faulty meters, if detected and replaced in short period of time (i.e. within a day or two), usually do not cause significant revenue loss to a utility. However, at LEC, the detection and replacement of faulty meters takes a long time (usually weeks and in some cases even months), which leads to revenue loss, normally due to customers bypassing the meters.

Tampered meters are those found to be bypassed (complete or partial) or its circuitry modified so that the meter records less than the consumed electricity. Free power meters are identified as meters that are faulty or non-recording, but supply continues to customer premises due to internal circuitry or hardware failure in the meter.

Thus, as per the available data, during March to November 2015 the number of meters replaced (faulty, tampered, and free power) is almost 62% of the number of new connections installed during the same period. It should be noted that the above data is for only nine months; if the trend continues, the meters replaced as a percentage of total number of connections will be closer to 20%.

LEC has not conducted any conclusive study or meter testing exercise to ascertain the causes of such a high faulty meter rate. However, LEC management revealed that the inferior quality of meters may be to blame. Recently, on request of LEC management, a technical team from Itron visited LEC and conducted studies to find the reasons for poor performance of the meters. Itron's report was not available at the time of writing this report.

The PATRP team collected data on ongoing theft reduction activities from the Energy Monitoring Section (EMS) of LEC. EMS is housed in LEC's Generation Department and reports to the Deputy Managing Director (DMD) Generation. Consistent data on theft reduction activities is available for the post-Ebola period only, and PATRP analyzed the data for the period June 2015 to February 2016. During this period, EMS and Commercial Technical inspected over 5,000 meter installations with findings shown in the table below:

Findings Category	Number
Tampered Meter	887
Faulty Meter	2,034
Free Power Meter	686
OK Meter	1,740
Total	**5,347**

EMS keeps data on inspection of suspected meters only when they are disconnected from field or customer premises. Hence, the actual number of meter installations visited may be much higher than reported. Data on the number of installations visited by the EMS and Commercial Technical teams during this period is not available. Further, sufficient information is not available on the following important aspects:

- Aging of faulty meter replacement is not available as the process is manual and paper-based. In many cases it takes more than six months for replacement of faulty meters, and customers have to pursue rigorously. In most cases, customers do not report faulty meters to LEC. The Commercial Department's almost non-existent data analysis capability is unable to identify faulty meters in the field.
- After detection of the faulty, free power, and/or tampered meters, limited analysis is done to assess the revenue lost due to these causes. There is no standard procedure to charge the customers for the time during which their meters were not working.
- In most cases, disconnection, theft assessment, and re-connections are not reflected back on the LEC IT system, making it difficult to assess the revenue recovery (if any) made on these cases.

Where assessment of revenue lost and revenue recovered through identified causes is not available, it is assumed that the number of these cases is directly proportional to the revenue lost due to these causes. Under these assumptions, the major reasons for non-technical losses are presented in the chart below:

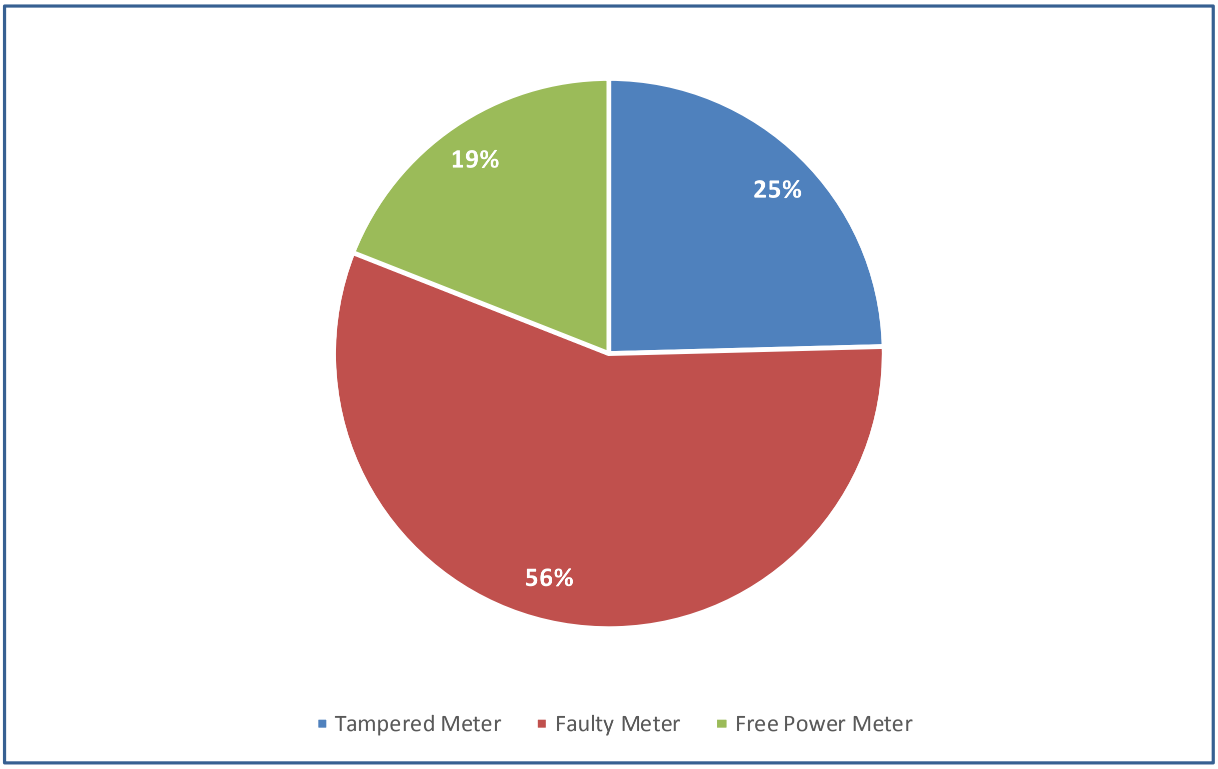


Figure 4-6: Causes of non-technical losses

As shown in the chart, the major contributor to non-technical losses is faulty meters, followed by tampered meters and meters giving free power to customers. Though factors related to energy meters seem to be contributing most to the non-technical losses, PATRP found that commercial processes implemented in LEC are very weak and ultimately result in revenue losses regardless of meter issues. Commercial processes are assessed in the next section, however some major process weaknesses that are leading to revenue losses are as follows:

- Commercial processes are manual and paper-based, resulting in applications for new connections and faulty meter replacement being delayed and sometimes lost. It is difficult to track applications once they have been submitted. It is difficult to obtain aging reports on applications as they are not tracked by any IT system. Customers who submit new connection or meter replacement applications may, therefore, indulge in electricity theft with or without connivance with utility personnel.
- While most of the customers are on pre-payment metering, there is very limited effort towards analyzing the exception reports from the Itron system, especially those related to customer vending aging, no vending, and low/high consumption. As a result, faulty, free power, and tampered meters remain undetected for long periods, leading to revenue loss.
- The revenue protection system in LEC is reactive and based on tip-offs rather than on energy meter analysis. This, coupled with non-implementation of an electricity balance system, hampers identification of high-loss areas where revenue leakage takes place.
- The PATRP team reviewed the LEC meter specifications and found them lacking. Given that Liberia does not have national metering, LEC should develop detailed metering specifications to include customized tamper conditions, environmental conditions, display parameters, material used in

manufacturing of meters, etc. In absence of detailed meter specifications, unsuitable meters are being procured, which results in high meter faults.

- There are very limited meter testing capabilities available in LEC. There is only one meter testing set available. As a result, tampered meters are not assessed for reduced recording of consumption. This also impacts the revenue recovery process from theft cases.
- The meter procedures related to installation practices are weak. There is no meter-sealing policy, which negatively impacts the revenue protection system.

4.4 CONCLUSION AND RECOMMENDATIONS

- The overall system losses (AT&C losses) in the LEC system are to the tune of 32%, of which technical and non-technical losses are 11.92% and 20.08%, respectively. Major reasons for non-technical losses are faulty meters, meter tampering, and meters giving free power to customers. There is limited reporting on direct theft of electricity from the LEC network.
- LEC should implement an electricity balance system by metering energy at generation units, incoming and outgoing feeders, and distributions transformers. This will help in identifying high-loss areas on which to focus revenue protection activities.
- There is immediate need to improve meter installation practices and to develop a meter-sealing management policy.
- The meter testing facilities need to be improved. This should include establishing a meter testing laboratory to ensure that all energy meters are tested and sealed before being distributed for installation. Further, more in-field meter testing kits should be procured for periodic testing of all three-phase meters and sample in-filed testing of single-phase meters.
- Detailed meter specifications should be developed for future procurements to ensure meters are suitable for operation in Liberia’s environmental conditions while providing sufficient protection against theft.

5. EVALUATION OF LEC COMMERCIAL SYSTEM

5.1 INTRODUCTION

The objective of this task was to review LEC's current commercial practices and activities and develop an assessment of their efficacy and security. PATRP gained understanding of LEC's commercial processes through meetings with the management team, including the CFO, the DMD Commercial, Customer Service Manager, IT Manager, Energy Monitoring Manager, and Energy Monitoring Technical Superintendent.

PATRP mapped the existing commercial processes, and this report provides recommendations on improving them. The legends used for process flows are shown below:

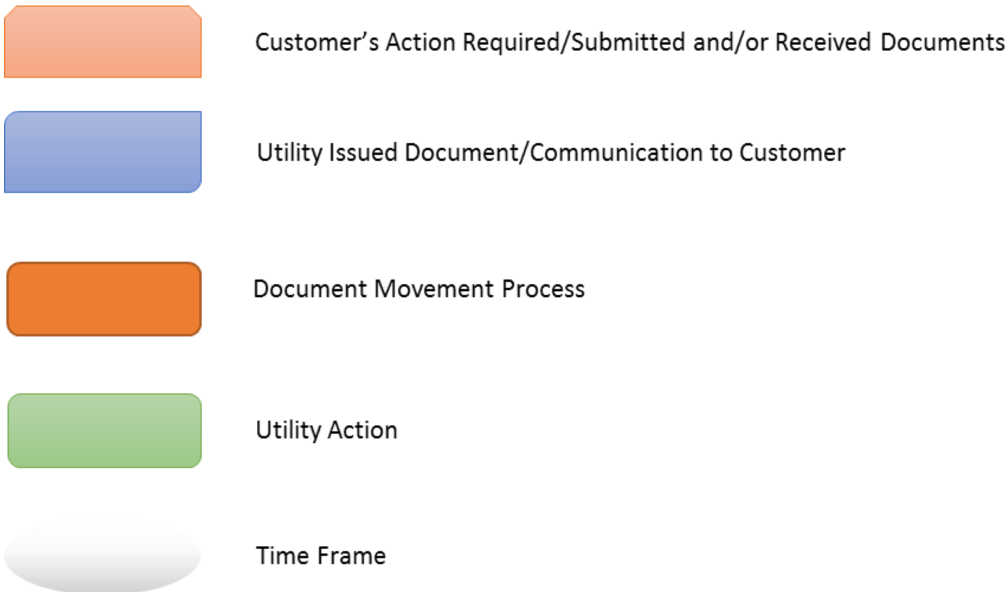


Figure 5-1: Legends used for process mapping

This section of the report should be read in conjunction with section 7.2.1, which talks about recommendations on restructuring the Commercial Department to bring focus on reduction of AT&C losses. The restructured Commercial Department needs to be supported by reengineered processes to be effective. Hence, the recommended process improvements in this section make reference to the recommended Commercial Department structure in Section 7.

5.2 REVIEW OF THE NEW CONNECTION MANAGEMENT PROCESS

5.2.1 Current Process

PATRP reviewed and assessed the new customer connections process and identified opportunities for improvement. The PATRP team mapped the process in detail with underlying timelines, and concluded that the process seems overly long. The prolonged delays in connecting customers to the grid lead to increased commercial losses. During the review, the PATRP team assessed options for introducing or enhancing service-level agreements with customers, an escalation mechanism for delayed connections, and follow-up mechanisms to reduce aging.

The new connection process is not documented in detail and ownership of the process is not clearly defined. Each application for new connections has a work order number that can be used for tracking. However, the process is manual and paper-based. Therefore, many customer applications are lost. In addition, it may take 5-6 months to obtain services from LEC, during which time customers may illegally connect to the grid. Many customers who are waiting for connection have already paid their connection charge.

LEC's Customer Services section (CS) receives customer applications for new connections, conducts application form review, and provides feedback to customers for properly completing the application. The New Services section (NS) is responsible for recruiting the customer and visits the customer premises to assess its readiness for connection. In case network augmentation or extension is needed, the applications are sent to the Transmission and Distribution section (T&D). The Commercial Technical (CT) is section is responsible for all metering activities.

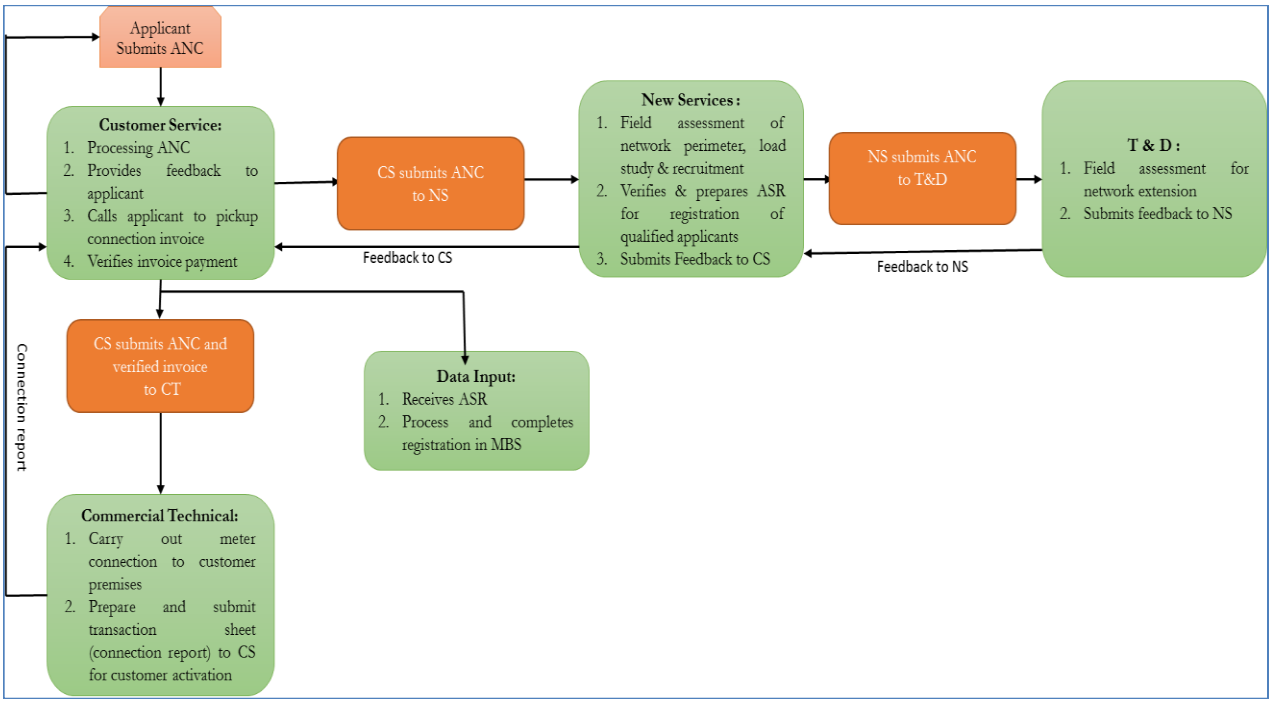


Figure 5-2: Existing new connection process flow

5.2.2 Suggested Improvement

PATRP recommends that the Customer Service section becomes the new connection process owner. The proposed new connection process is shown in the flow chart below:

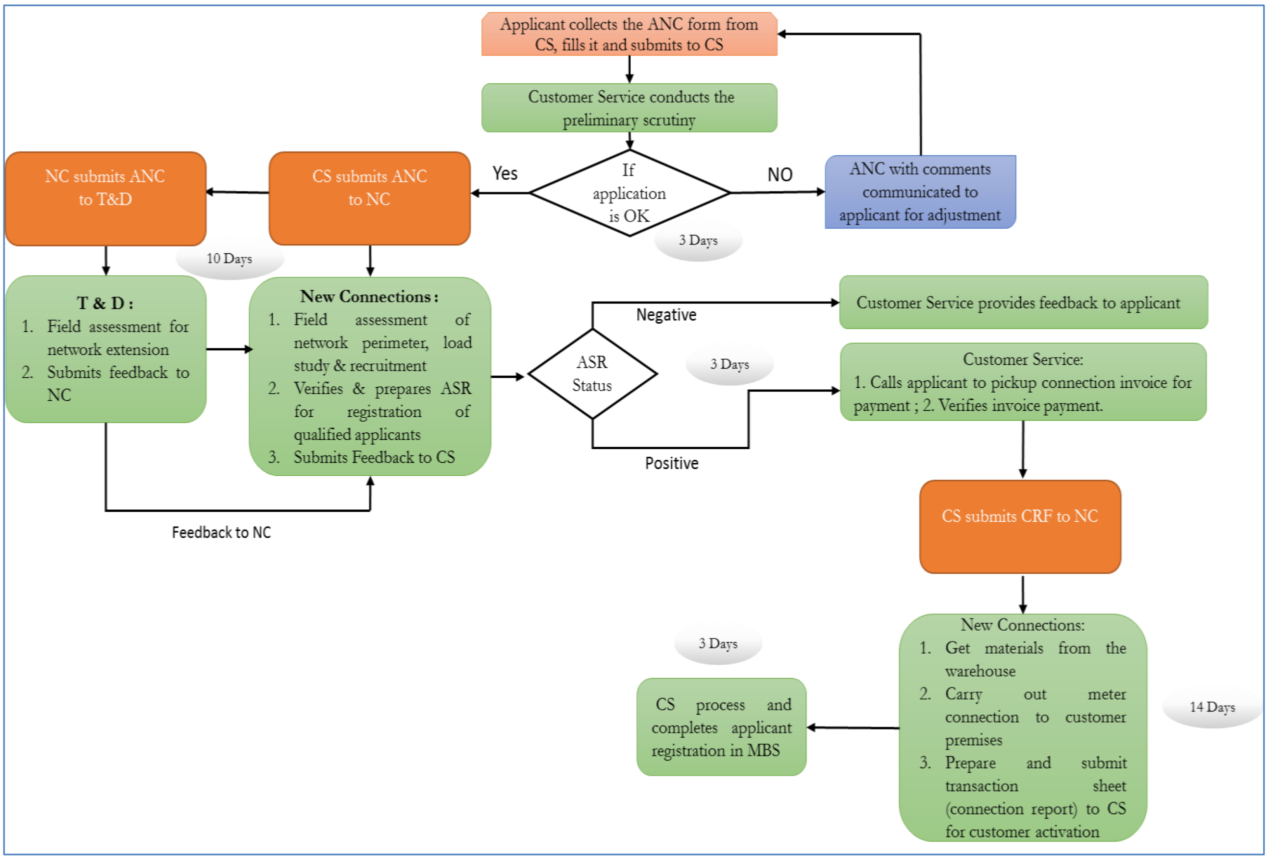


Figure 5-3: Recommended new connection process

The proposed process will provide clarity on the process ownership. Customer services is proposed to be the process owner of the new connections process and will coordinate with all other internal departments to get the work done. LEC internal departments such as T&D and New Connections will become service providers to Customer Services with well-defined service level agreements. Customer services will proactively communicate customers on the progress of their new connection requests.

5.3 REVIEW OF READING, BILLING AND COLLECTION FOR CT CONSUMERS

PATRP examined the reading, billing, and collection cycle for CT and post-paid customers to propose recommendations for more efficient management arrangements. During the scrutiny, the advisory team reviewed the process of detecting, informing, and correcting customers in the billing database, as well as the behavior of budgetary customers. PATRP gave particular attention to energy sales to government clients, streetlights, hospitals and other types of accounts that typically present collection problems.

5.3.1 Current Process

LEC has four meter readers for post-paid customers. These meter readers read all 354 post-paid customers in two days. However, together with reading verification it can take up to a week to enter all data into the system.

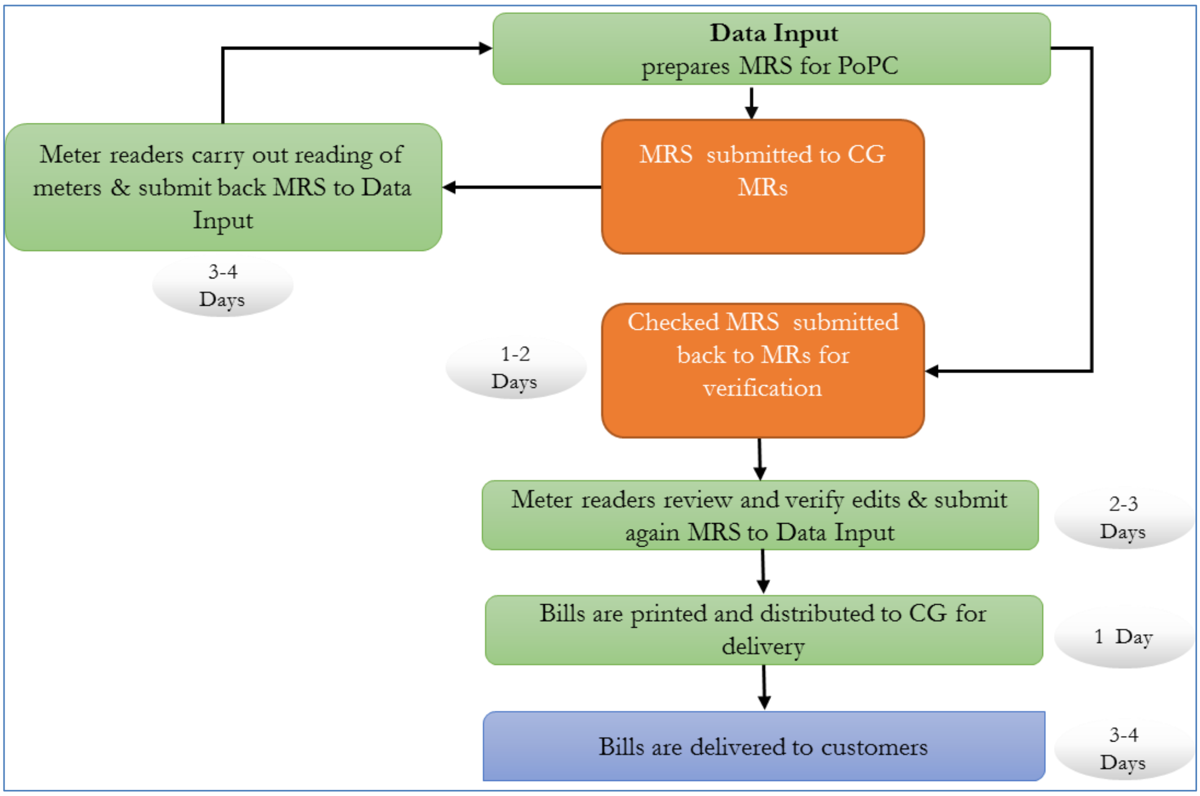


Figure 5-4: Current post-paid customer meter reading process

The disconnection and reconnection processes for non-payment is not clearly defined and practiced in LEC. As in most of other cases, the process owner is not clear. Criteria for disconnection and reconnection orders can be set by Billing and Customer Care, and issued by Data Input/IT. There is limited monitoring for disconnected customers.

The present disconnection and reconnection process flow chart is shown below.

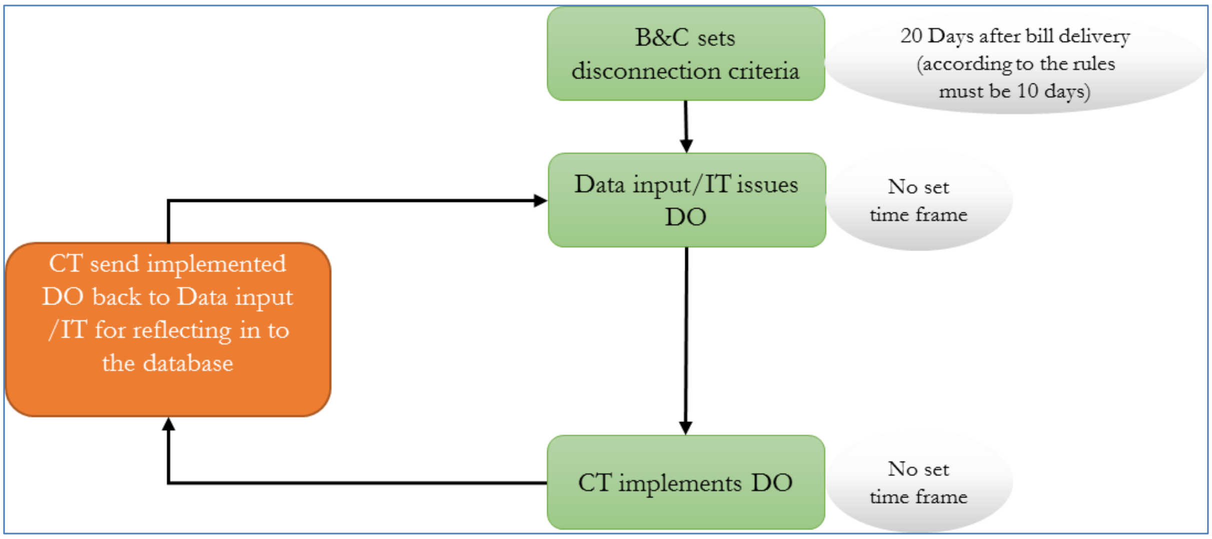


Figure 5-5 : Current customer disconnection process

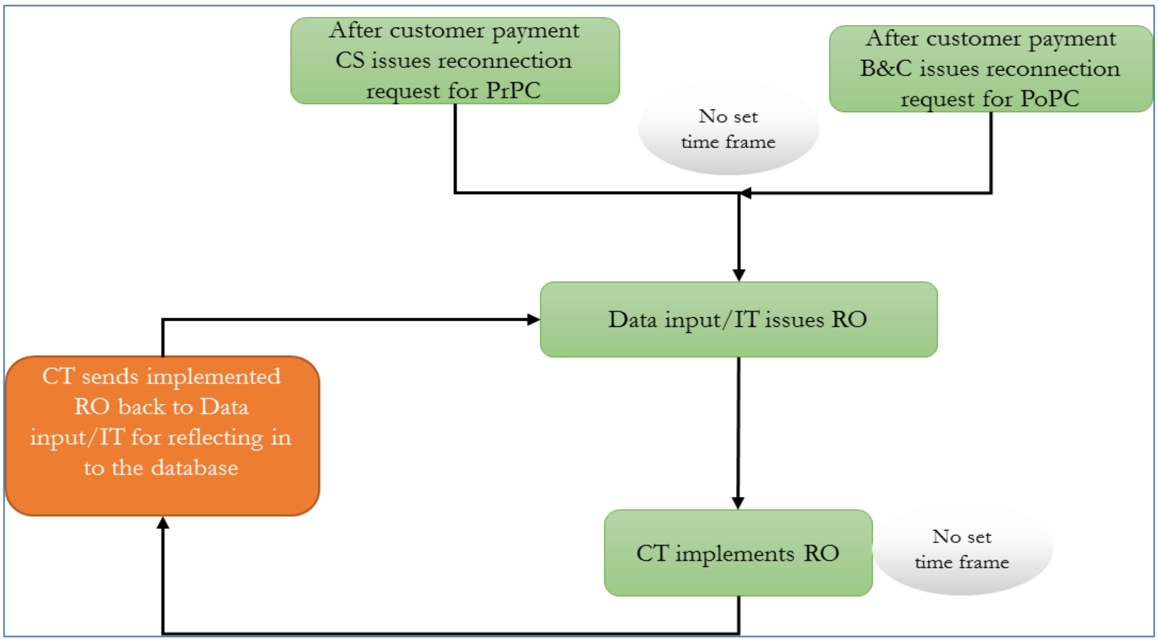


Figure 5-6: Current customer re-connection process

5.3.2 Suggested Improvement

PATRP feels that there is very limited analysis of customer data, and hence recommends creation of an Analysis division within the Billing section. The responsibility of the staff involved in the Analysis section will be to analyze the consumption pattern of customers and identify suspected theft or electricity pilferage cases. The Analysis group will also support quality control of reading and billing processes. PATRP recommends that a new Billing and Analysis (B&A) section be the owner of the billing process (printing the reading list, checking the correctness of provided data, printing the bills, preparing disconnection/reconnection orders and so on). Implementation responsibility for this process would be assigned to the Commercial Technical Department.

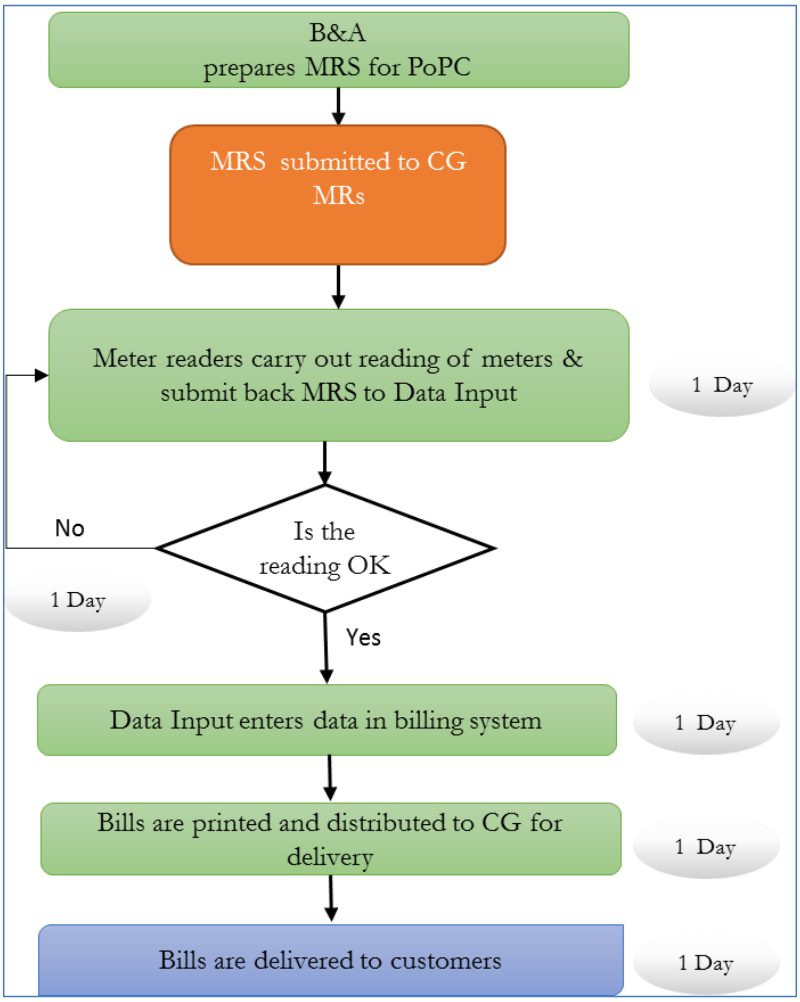


Figure 5-7: Proposed meter reading process for post-paid customers

During the reading, STs must verify meter number, seals, defect, damage or tampering possibilities. In case the current reading is the same as the previous reading, STs must provide additional explanation for non-consumption (i.e. empty, destroyed, abandoned premises etc.) in MRS. In case of no access to customer meter, STs must indicate in MRS whether customer is consuming energy or not.

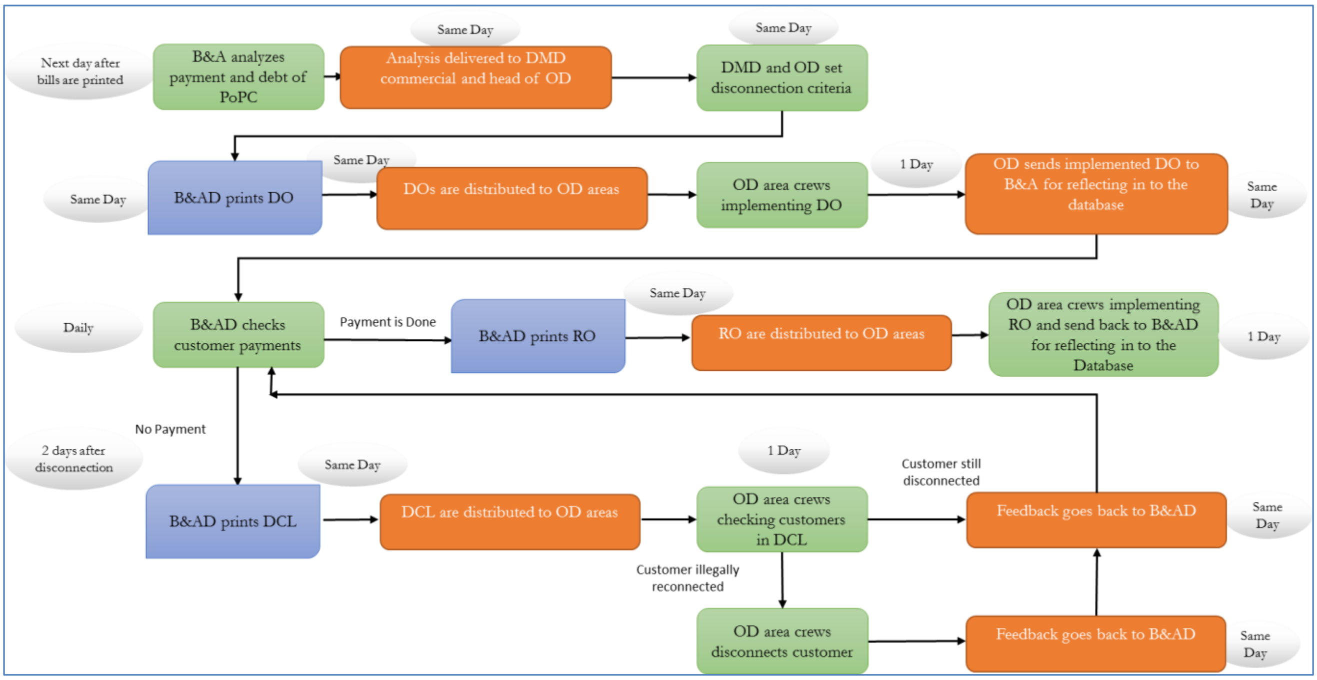


Figure 5-8: Proposed disconnection and re-connection process for post-paid customers

5.4 REVIEW AND ASSESSMENT OF THE REVENUE PROTECTION PROCESS

PATRP reviewed reports produced by LEC's Energy Monitoring Section (EMS) and conducted field visits in downtown Monrovia with unit employees. In LEC's organizational structure, EMS is under the Generation Department, which is not a practical choice for effective theft control activities. Commercial Department does not have responsibility for commercial losses caused by electricity theft.

5.4.1 Current Process

At this stage, EMS work is not planned. Theft control activities are mostly driven by information provided by customers, or experience and common knowledge of problematic areas.

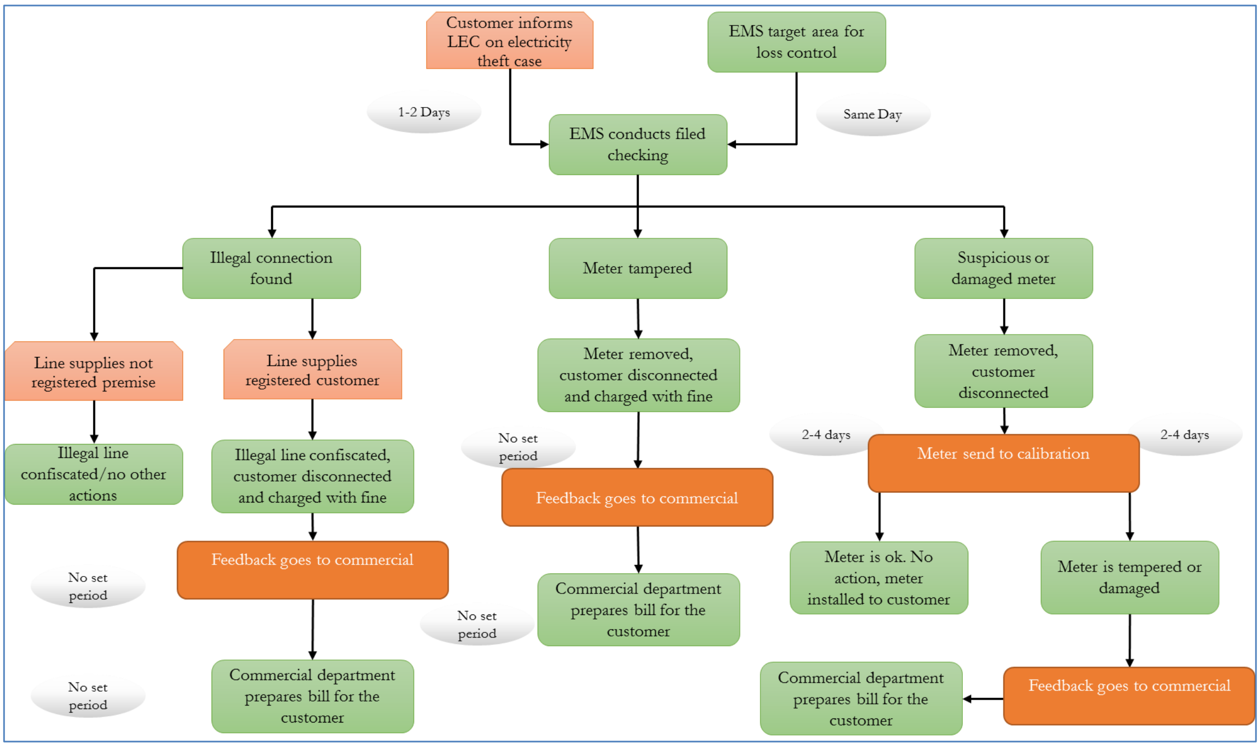


Figure 5-9: Present revenue protection process

5.4.2 Suggested Improvement

PATRP recommends a robust revenue protection process that is based on data analytics and that provides strategic direction for loss reduction. The basis for this revenue protection process is implementation of an energy balance system where incoming and outgoing energy at major network nodes such as feeders and transformers are monitored. The process starts with identification of losses in the LEC system and identification of high-loss distribution transformers. The recommended process is shown in the figure below.

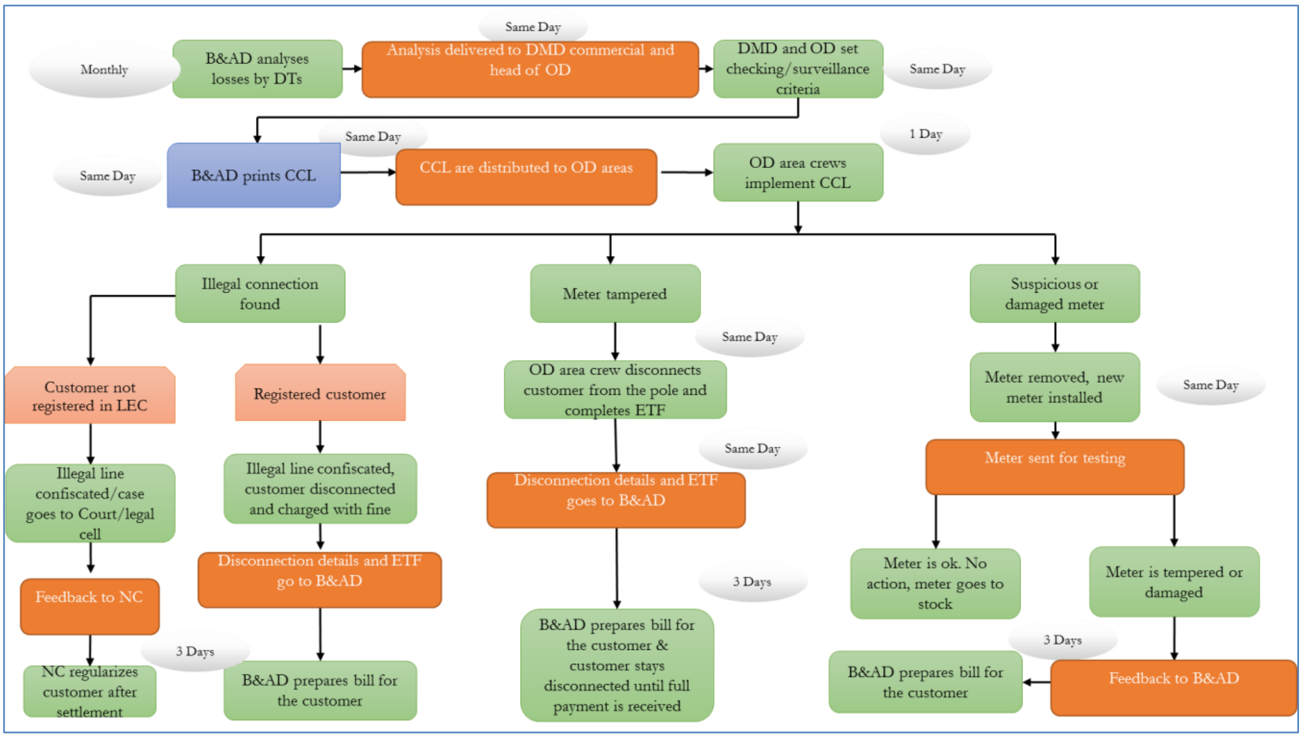


Figure 5-10: Recommended revenue protection process

5.5 CONCLUSIONS AND RECOMMENDATIONS

- Commercial process are manual and paper-based and have not been documented in detail. As a result, new connections are delayed and customers may indulge in electricity theft.
- Customer care processes are also paper-based, and though customers are provided work order numbers for their complaints, tracking complaints is difficult.
- The revenue protection system is not based on analysis of data from post-paid or pre-paid systems, and primarily operates based on tip-offs from customers.
- The present IT system in LEC does not have process flow capability and hence tracking work-order numbers is not easy. As a result, information on the aging of work orders or customer requests is not available from the system.
- PATRP recommends that LEC procures a comprehensive Customer Management System (CMS) that has best practices based on commercial processes.

6. FUEL MEASUREMENT AND ACCOUNTING

6.1 INTRODUCTION

The purpose of this task was to review and assess the fuel delivery, storage, and measurement practices and recording processes of LEC generating stations to evaluate the potential errors and discrepancies between fuel delivery and consumption records.

At present, LEC is supplied from three generating plants, described below:

- The Bushrod Island generating station consists of fifteen 1 MW units. Ten units were provided by USAID and five by Norway. Eleven units are currently operational. The plant is equipped with fifteen 10,000-gallon fuel tanks.
- The Congo Town plant consists of two 1 MW units (both are operational) and is equipped with one 8,000-gallon, one 5,300-gallon, and one 900-gallon fuel tank. This generating unit is a baseload plant.
- The Kru Town plant consists of five 1 MW units equipped with five 10,000-gallon fuel tanks. Only two units are operational.

The total output from the 15 operational units is around 11 MW.

There are currently five generation projects underway which will substantially increase LEC's generation capacity in coming years:

- In February of 2016, the LEC commissioned the World Bank funded 10 MW Heavy Fuel Oil (HFO) Plant. At the time of writing of this report, the plant was under suppliers operations and not yet handed over to LEC.
- GOL-funded 18 MW HFO Plant was under commissioning at the time of writing this report.
- Ongoing construction work on a 10 MW HFO Power Plant, funded by the JICA, is expected to be completed by September 2016.
- A 10 MW HFO plant funded by Arab Bank for Economic Development in Africa (BADEA) will be completed in 2018.
- Ongoing work for the rehabilitation of the Mt. Coffee hydropower plant is moving forward, with completion of the first unit expected by the first quarter of 2017.

6.2 FUEL MEASUREMENT AND RECORDING

As mentioned above, Bushrod, Congo Town, and Kru Town generating stations provide electricity to LEC customers. Figure 6-1 shows the fuel storage and piping system in these generating stations. Though the generating stations have different number of generating units with different capacities of the storage tanks, the schematics for the storage, piping and measurement remains similar to that shown in Figure 6-1.

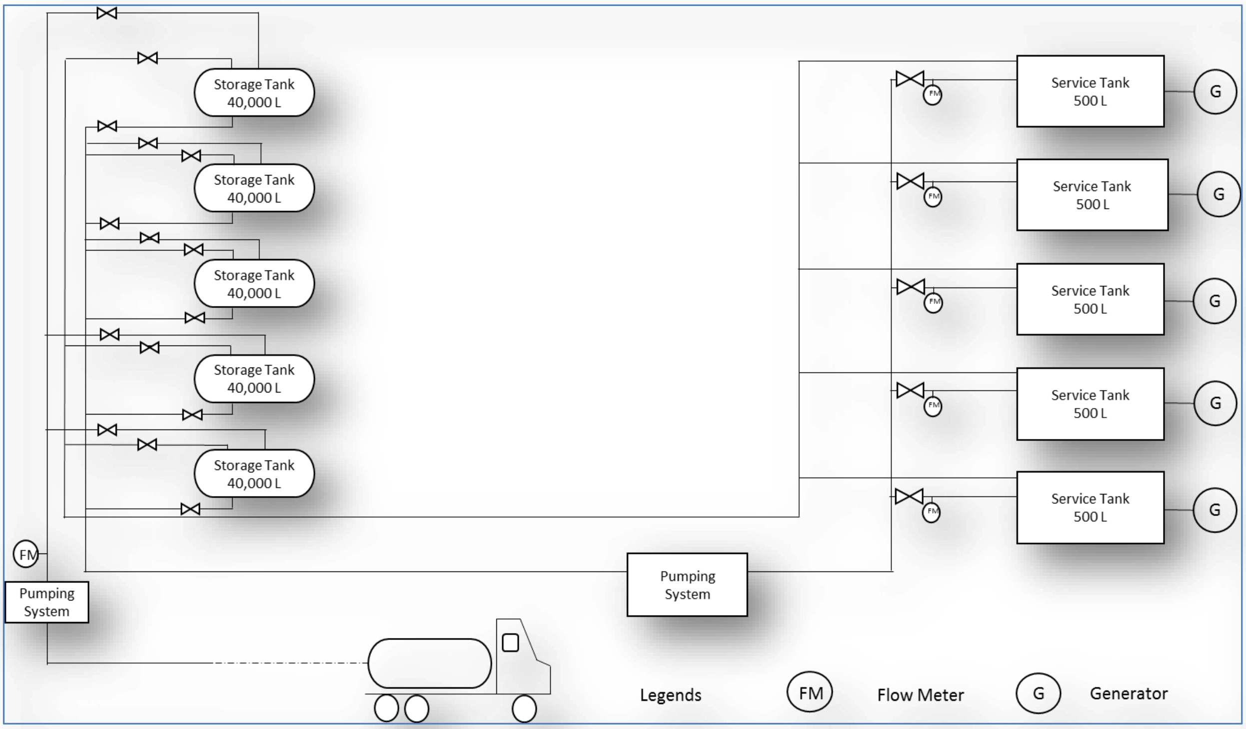


Figure 6-1: Typical fuel piping and storage system in LEC

The fuel delivery, storage, and measurement system is described below:

- The generating plants are under CCTV surveillance and all entries and exits are monitored.
- Srimex supplies fuel to these plants in fuel trucks specially allocated for LEC. These trucks are sealed by Liberia Petroleum Refining Company (LPRC). Around 400,000 gallons of fuel is used in a month. The capacity of LPRC/Srimex tankers is 5,000 Gallons.

Figure 6-2 : Srimex fuel truck at Bushrod plant

- Seals on fuel trucks are checked by authorized LEC personnel before supply is received. Upon confirming that seals on the fuel tanks are not tampered, the truck outlet is connected to the main flow meter and supply is taken. However, LEC personnel doubt the accuracy of the main flow meter and hence its reading is not taken into account to measure the quantity of fuel received. Rather, a 'dip-stick' method is adopted to measure the change in storage fuel tank levels. The difference in fuel storage tank level of all connected storage tanks is considered as the quantity of fuel received. The received fuel quantity is noted in log-books and kept as records.

- The fuel consumption by the generating plant is calculated by taking into account the change in readings of the flow meters (over 24-hours) connected to the 'Service Tanks' or 'Daily Tanks' minus any remaining fuel in these tanks. The quantity of remaining fuel in the service tanks is obtained from the reading of transparent capillary tubes attached to the service tanks.

Figure 6-3: Flow meter (FM) at service tank

- LEC calculates the fuel consumption by dip-stick method as well. The fuel levels in storage tanks are noted every morning and night by dip-stick method. The change in fuel level of all fuel storage tanks is calculated and is then considered as fuel consumption.
- The quantity of fuel consumed as obtained by the two methods is compared to assess the variation. However, for reporting purposes, the consumption arrived by flow meter readings is used.
- The daily fuel consumption of the generators is noted in a log-book for records.

Key issues observed

- Different measurement methods are adopted for delivery and consumption of fuel. While delivery of fuel is taken based on the dip-stick method, the consumption of fuel is measured by flow meters. The flow meters installed in the generating stations are of accuracy class 0.5, which means that maximum error in measurement can be ±0.5% of the actual consumption. On the other hand, the dip-stick method is a very crude method wherein the measurements can vary depending on the personnel doing the measurement. As both measurement methods are different, there is high possibility of discrepancy in delivered and consumed fuel quantities.
- The flow meters in the generating plants have not been calibrated since installation, and hence probability of error in readings provided by these flow meters is very high.
- The 'dip sticks' used for measuring the fuel in storage tanks are not calibrated.
- The storage tanks have not been cleaned since their installation. As a result, there is possibility of thick sludge formation at the bottom of the tanks causing errors in dip-stick readings.
- The readings noted on the log-books are not digitized as per the format, rather only a summary of the readings is noted on MS Excel sheets that are prone to errors. There is limited effort towards verifying and authenticating the readings noted on the log-books.

6.3 ANALYSIS OF FUEL SUPPLY AND CONSUMPTION

PATRP collected and analyzed fuel supply and consumption data for the one-year period of November 2014 to October 2015 to account for seasonal variations. On average, the three plants together consume around 380,000 gallons of high speed diesel (HSD) every month. The difference between fuel supplied and fuel consumed stands around 3% of the supplied fuel, which would be enough to run the three power plants for additional 11 days in a year. The table below provides summary of the analysis:

Table 6-1: Fuel supply and consumption analysis

Generating Plant	Fuel Supplied	Fuel Consumed	Supply Vs Consumed		Plant Efficiency	Days Equivalent of Fuel loss
Congo Town	567,470	545,751	21,719	4%	14.54	13.97
Kru Town	891,295	859,106	32,189	4%	12.57	13.18
Bushrod	3,264,044	3,172,213	91,831	3%	12.50	10.27
Total	**4,722,809**	**4,577,070**	**145,739**	**3%**	**12.75**	**11.26**

The analysis shows that the Congo Town plant is the most efficient, followed by Kru Town and Bushrod. Congo Town is operated as a baseload plant while the other two plants cater to the variations in demand (which explains the higher efficiency at Congo Town). The fuel loss across the three plants is between 3%-4%, which should be sufficient to run the power plants for additional 12-14 days in a year.

The fuel loss at the power plants is a concern, and a few sporadic instances of fuel thefts have been reported, especially at Congo Town, which has the lowest surveillance among the three plants. LEC intends to move the generating units from Congo Town to Bushrod area, which should resolve the issues related to fuel theft.

However, PATRP feels that the 3%-4% fuel loss cannot be attributed to theft as all three plants show similar fuel losses over the one-year period and stringent surveillance at Bushrod and Kru Town deter fuel theft. This points to more a systematic trend in fuel losses, which can be due to the different methods of measuring supply and consumption being used by LEC (as explained in the previous section).

The graphs below provide trends in fuel supplied, fuel consumed, and plant efficiency (kWh generated per gallon of fuel) in the three power plants.

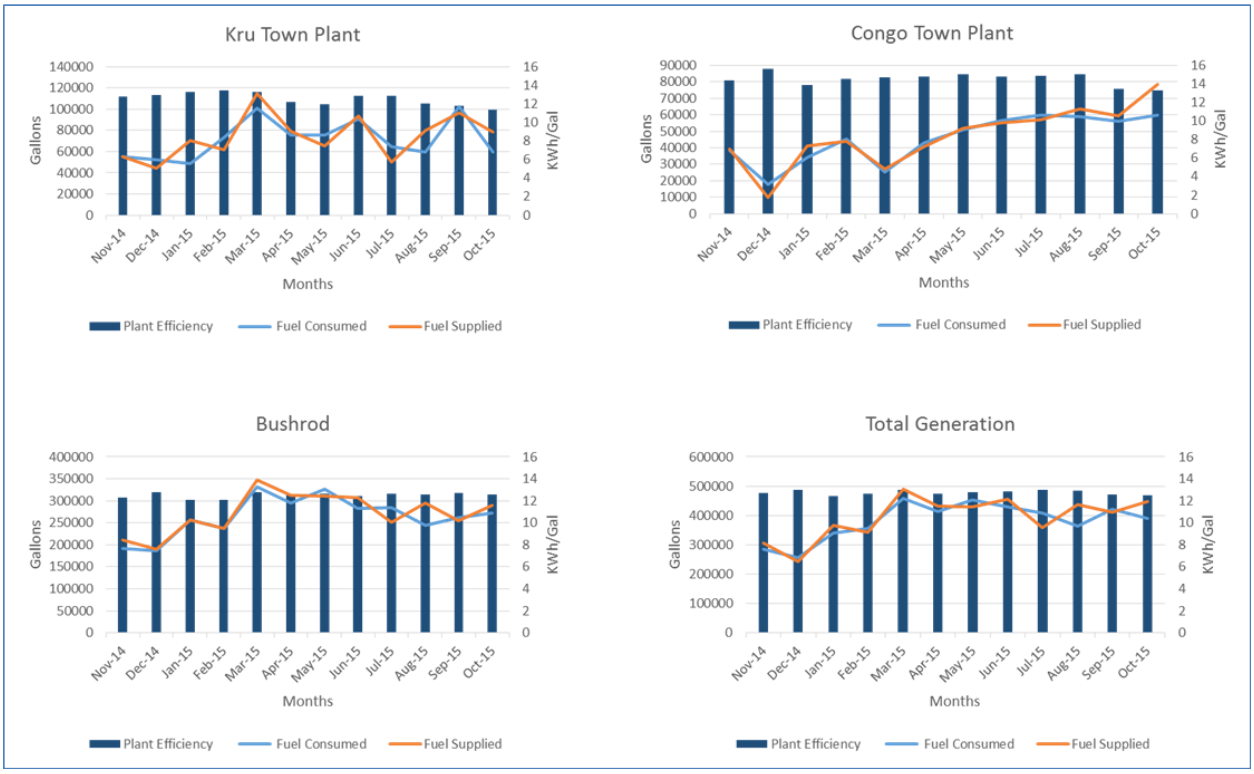


Figure 6-4: Fuel supply, consumption and plant efficiency

The graphs above show that fuel supply follows consumption very closely for Congo Town power plant, while for Kru Town the correlation seems quite poor, indicating that there is more certainty in operation of Congo Town. This is supported by the fact the plant is operated as a baseload plant while Kru Town is used to meet peak variation. In general, at Bushrod plant the fuel supply closely follows consumption, indicating that the generating units are used as baseload, as well as to meet variations in demand.

There is no forecasting model being used to estimate the quantity of fuel needed by the power plants for the day or week ahead. LEC needs such a model as new plants are being added and managing and balancing supply and consumption will become complex in the coming years.

As per LEC's existing plan, these three plants will be operated as backup plants from the end of 2016 when new generation from the World Bank-, GOL-, and JICA-funded plants come online.

6.4 CONCLUSION AND RECOMMENDATIONS

- The annual fuel loss in the generating plants is sufficient to run these plants for 12-14 additional days.
- The major cause of discrepancy between supply and consumption of the fuel is different methods of measurements adopted by LEC. While supply of fuel is measured by dip-stick method, its consumption is measured by flow meters of accuracy class 0.5.
- The fuel supply and consumption records are not digitized.
- LEC should get the fuel tanks cleaned periodically.
- The faulty fuel meters in the generating stations should be replaced, and
- The flow meters should be calibrated annually.

7. LOSS REDUCTION PLAN DEVELOPMENT

7.1 INTRODUCTION

This section builds upon the findings of the previous sections and identifies initiatives that should be undertaken to reduce technical and non-technical losses in the LEC system. This section also develops an investment plan and implementation roadmap for the identified initiatives.

As discussed in Section 4, the overall LEC system loss is 32%, of which technical loss is around 11.92% while non-technical loss is 20.08%. Thus, most of the system loss is non-technical, which is evident from misaligned organizational structure, weak commercial processes (metering, billing, revenue protection, etc.), and limited capacity building. The following sections identify the necessary interventions, estimate the investment required, and provide an implementation plan for the interventions.

7.2 PRIORITY ACTIONS FOR LOSS REDUCTION

PATRP identified many interventions that should be initiated to reduce losses in the LEC system. These interventions relate to many functional areas of LEC, including commercial processes, network management, and capacity building. The priority actions for loss reduction are listed in

Table 7-1 below.

Table 7-1: Priority actions for loss reduction

	Priority Actions
1.	**Realign Commercial Department per organizational and customer needs**
1.a	Restructure with a focus on reducing AT&C losses
1.b	Create large customer group
1.c	Increase focus on community customers
1.d	Give ownership of pre-payment metering system to Commercial Department
1.e	Develop data analytics to support revenue protection
1.f	Improve pre-payment vending system and corporate branding
2.	**Improve current metering system**
2.a	Strengthen meter specifications
2.b	Develop and implement a comprehensive meter sealing system
2.c	Enhance meter testing capabilities
3.	**Implement Automated Meter Reading (AMR)**
3.a	Move all large customers to AMR
3.b	Move feeder and DT metering to AMR
4.	**Implement Energy Balance System**
4.a	Implement EBS at 66kV and 22kV
4.b	Complete DT metering
4.c	Implement customer mapping and enumeration
5.	**Procure a comprehensive commercial IT system**
5.a	Implement CMS and ERP
5.b	Integrate CMS with AMR, Itron Pre-payment system and GIS
5.c	Implement DMS
6.	**Improve fuel accounting system**
6.a	Do periodic cleaning of fuel tanks
6.b	Calibrate and test flow meters periodically
7.	**Build capacity of staff**
7.a	Train staff on meter data analysis, meter testing, and revenue protection
7.b	Train staff on electricity balance calculations and troubleshooting
7.c	Conduct exposure visits to utilities with strong commercial systems
7.d	Provide more training on ArcGIS® and network modelling & simulations
7.e	Build capacity in customer care and outreach
7.f	Training on O&M and safety

The priority action items listed in the table above are discussed in more detail below:

7.2.1 Realign Commercial Department as per organizational and customer needs

1.a: Restructure with a focus on reducing AT&C losses

The present structure of LEC Commercial Department needs restructuring to bring focus on loss reduction. The present structure is shown in figure 7-1 below:

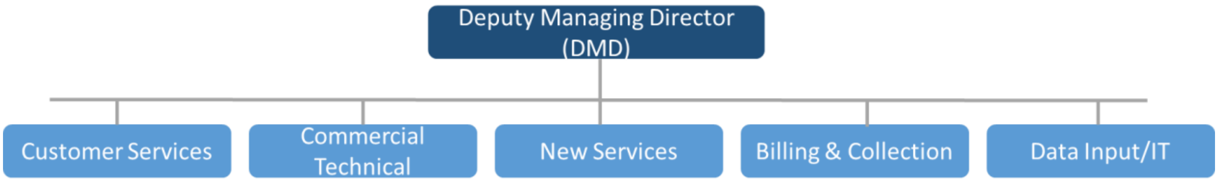


Figure 7-1: Present LEC Commercial Department structure

The functions for various sections within Commercial Department are as follows:

- The Customer Services section is responsible for managing customer care, complaints/requests, developing/documenting commercial processes, and generating commercial tracking reports.
- Commercial Technical handles all metering services, including meter installation, replacement and testing.
- New Services is responsible for recruiting customers for new connections and conducting preliminary assessment of customer premises to ascertain availability of distribution transformers, lines, etc., for executing the new connections. It also conducts quality control of new connections done by contractors.
- The Billing and Collection section does meter reading, prepares electricity bills and manages collection for post-paid customers.
- The Data Input/IT section is responsible for feeding commercial data and information into the LEC IT system.

Though the above structure reflects the different functions of the Commercial Department, it does not indicate who is responsible for losses. During interaction with LEC management and staff in various departments, the PATRP team discovered that the responsibilities related to tracking and reducing losses is not entrusted to any specific department, and hence is a general responsibility of all departments and staff.

As non-technical (commercial) losses are a major contributor to total system losses, PATRP suggests a reorganization of the Commercial Department structure to ensure focus on loss reduction. The Commercial Department should become the owner of all commercial processes, including the pre-payment metering system and theft identification and reduction (at present this function is performed by EMS, which is under the Generation Department). The proposed Commercial Department structure is shown in Figure 7-2 below.

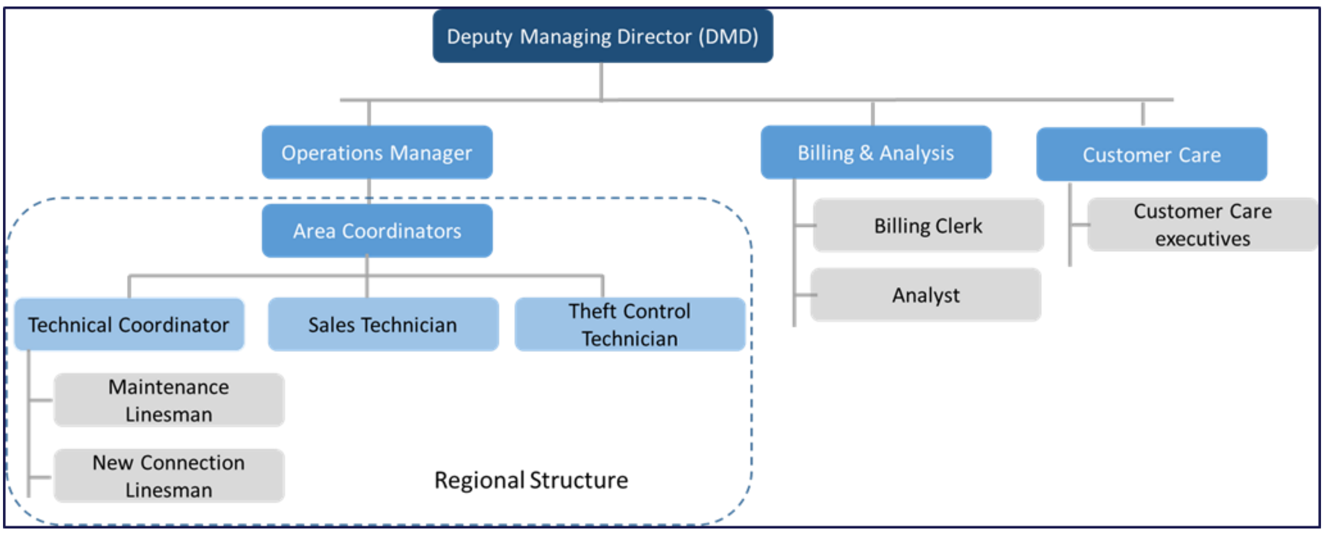


Figure 7-2: Suggested new structure of LEC Commercial Department

As shown in the figure above, PATRP recommends segregating the commercial functions into the following three sections:

- Operations
- Billing and Analysis
- Customer Care

PATRP recommends that the Operations unit be the backbone and implementer of LEC core commercial activities, including low voltage maintenance (which otherwise is included into T&D or grid functions in some utilities). It is also suggested that the regional structure shown in Figure 7-2 be created for each 66 kV substation area. Thus, at present, four regional structures should be created for Bushrod, Capitol, Kru Town and Pennsville substations. Area coordinators, with their crews, will be accountable for all energy delivered to the 22 kV feeders, billing and collections, disconnections and reconnections, LV maintenance, new connections, and enforcing payment discipline in their substation area.

The proposed Billing and Analysis section will function as the 'brain' of the Commercial Department, providing data analytics services for identification of theft, revenue leakage and errors.

The proposed structure will function with focus on loss reduction, as shown in the figure below.

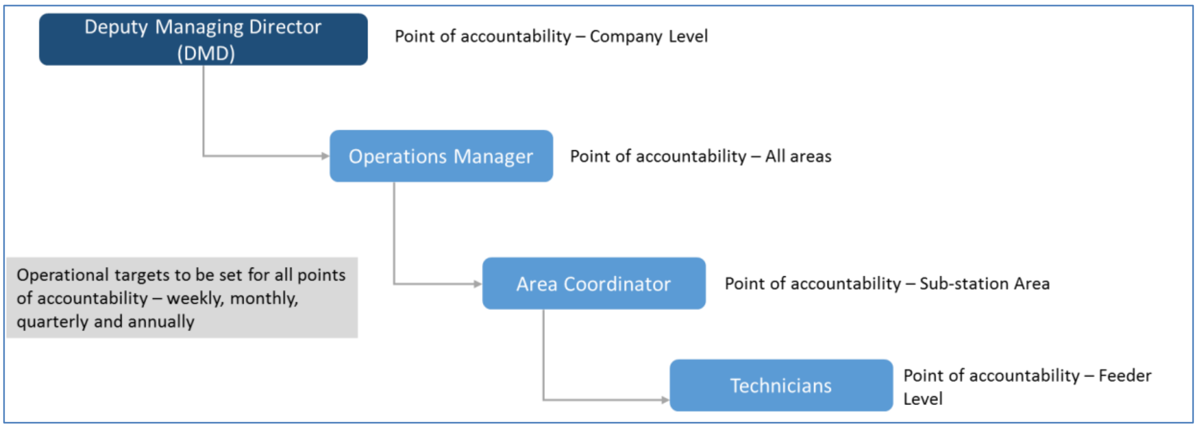


Figure 7-3: Functioning of new commercial structure with focus on losses

PATRP believes that restructuring the Commercial Department will not require substantial investments and can be achieved by reorganizing current functions, human resources, and other resources.

LEC should create a 'Model Region' and implement a loss reduction pilot to test its effectiveness. PATRP recommends that such a model structure should be created in the Bushrod Island substation area.

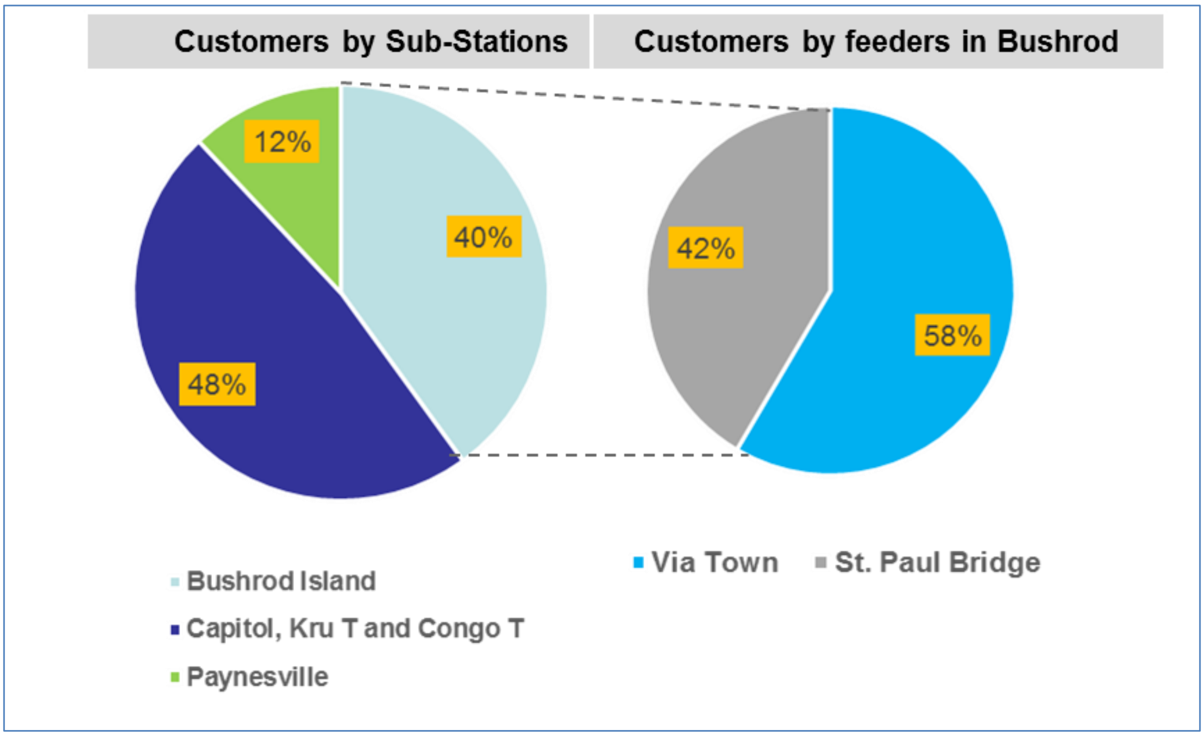


Figure 7-4: Loss reduction pilot area- Bushrod Island

The Bushrod substation area serves over 40% of the LEC customer base while contributes only 15% to its revenues. Low contributions to the LEC revenues from this area can be attributed partly to the large number of community connections. However, this area has a sufficient number of residential and commercial connections, and thus represents a good mix of customers for a pilot. If the entire Bushrod substation area seems too large for the pilot, LEC should select any one of the Via Town or St Paul Bridge feeders for the pilot. The recommendations of this study should be implemented in this pilot area and should include at least the following activities:

- Install energy meters at generators, 66kV and 22kV feeders and distribution transformers
- Complete customer indexing or mapping with distribution transformers
- Conduct energy balance calculations
- Identify high loss distribution transformers
- Initiate targeted loss reduction activities including meter testing, sealing , replacements and surveillance
- Monitor losses on a bi-weekly and monthly basis during the pilot implementation period of six months

The lessons learned from the pilot should be used to fine-tune the regional structure and loss reduction priority actions.

1.b: Create a large-customer group

One of LEC's priorities is to improve the sustainability of business by recruiting more large customers into its sales mix. However, there seems to be very limited focus on these customers. PATRP recommends that a separate unit is created within LEC's Commercial Department to cater to large customers.

At present, large customers on post-paid meters are only 1% (around 354 connections) of the customer base, but contribute roughly 40% of the revenue. As per the Electricity Master Plan (EMP)

2015 update, another sixty-seven (67) large customers with a cumulative load of around 49.7 MW will be added to the LEC network. In order to aggressively recruit and connect these customers to the network, it is essential that a dedicated group is formed to cater to the needs of these large customers. Large-customer characteristics are different from other customer segments and need more individual attention and outreach. Keeping these aspects in view, LEC should create a large-customer group. The key responsibilities of this group should be:

- Billing , collection, and customer service for large customers
- Meter testing, meter data analysis, and detection of theft cases
- Implement AMR/AMI in large customers and troubleshoot
- Implement AMR/AMI installations for Energy Balance System
- Conduct energy balance calculations

At present, the group can consist of three managerial staff (excluding the meter readers) that can be further expanded as the workload increases. The responsibilities of the managerial staff should be:

- *Managerial Staff 1*: Customer recruitment (new connections), AMR/AMI installations and troubleshooting.
- *Managerial Staff 2*: Billing, collection and customer care for large customers.
- *Managerial Staff 3*: Meter data analysis, theft detection and electricity balance calculations.

It is believed that for a small system such as LEC, the large-customer group should also be able to do the electricity balance calculations, as the group is custodian of all CT meter connections. The group will share the monthly losses calculations with higher management and area directors for follow-up actions.

Further, it is expected that LEC will identify staff within the organization and mobilize them in the large-customer group. Any increase in expenses can be met from LEC operations.

1.c: Increase focus on community customers

Community connections are a substantial part of the LEC customer base and are characterized by a low-income, low-consumption population. This segment is more prone to indulge in electricity theft due to lack of resources, limited reach to LEC, and political patronage. LEC needs to increase outreach to these customers and make services available to them easily to prevent them from indulging in illegal means of obtaining electricity. Outreach options can include the following:

- Conduct regular new connection camps in communities to ensure that all homes have legal electricity connections.
- As part of the offering, LEC may provide house wiring services, as most community houses do not have the necessary internal wiring to facilitate new connections.
- Ensure that pre-payment vendors exist near each community. This segment may not be sufficiently technology savvy to do recharges by phone or via internet banking. If a vendor cannot be situated nearby, weekly mobile vending systems should be made available to the communities.
- Offer corporate social responsibility (CSR) to community customers, which may include vocational training, education support, and consumption-linked insurance products etc.

PATRP believes that the outreach to community customers can be managed by LEC with existing resources.

1.d: Give ownership of pre-payment metering system to Commercial Department

At present, there is no clear owner of the pre-payment metering process. There is ambiguity between commercial, finance and IT teams related to process responsibilities and ownership. PATRP recommends that the Commercial Department is made owner of the pre-payment process and vendor management. Finance and IT should act as service providers to the Commercial Department. The functions can be separated as follows:

- The Commercial Department is the pre-payment process owner and single point of contact with Itron for all communications for all operational matters. The Commercial Department should engage with pre-payment vendors to improve customer service and corporate branding.
- Finance should conduct daily reconciliation of accounts with Itron and mobile/net-banking gateways and provide information to top management and the Commercial Department.
- IT should maintain the Itron software/hardware and control authorized access based on Commercial Department's recommendations. IT should also provide a monthly report on billing and collections; however, the Commercial Department should develop its own capabilities for fetching data from Itron system and conducting analysis for theft detection.

1.e: Develop data analytics to capability to support revenue protection

At present, the Energy Monitoring Section (EMS) is responsible for revenue protection activities, including theft detection. However, the section's activities are not guided by analysis of meter or consumption data, but rather by tip-offs from different sources. This is a reactive approach to revenue protection and does not necessarily lead to loss reduction. LEC needs to implement revenue protection activities for targeted loss reduction wherein a particular geographical area with high losses is selected (based on analysis of consumption data of customers in that particular geography). In particular, the following analysis should be conducted to support the revenue protection activities:

- *Consumption Analysis:* Consumption analysis is key to identification of theft cases. LEC should identify cases where customer consumption has declined from the last one-year baseline. LEC should use a format similar to

- Table 7-2 for identifying customers on each feeder whose consumption has dropped by 5%, 20%, 50%, or more. The immediate priority of LEC should be to investigate the cases where consumption has dropped by more than 50%, followed by cases where consumption has dropped by 20% to 50%.

Table 7-2: Report Format for Consumption Analysis

Feeders	Consumption Analysis - 1 Year History Baseline			
	No. of consumers with % reduction in consumption			
	< 5%	5% to 20%	20% to 50%	More than 50%
Feeder 1				
Feeder 2				
Feeder n				

The information should be tracked on a monthly basis to ensure that the number of customers decreases in each category. This report should be easily extracted from the Itron pre-payment system. PATRP requested that the LEC IT team extract data in the above format, but the data could not be provided during this assignment.

- *Monitoring of recharge token purchase history:* An Itron analysis reports indicates that, on average, only 50% of pre-payment customers recharge their meters every month and that the average transaction size is $16 (equivalent to around 32 kWh at the current tariff). Some 200,000 transactions occur every month, which translates into monthly consumption of around 52 kWh per customer per month. This level of average consumption is very low, indicating that there is electricity pilferage from the LEC network. PATRP recommends that LEC conduct analysis of token purchase history to identify suspicious cases. LEC may use a format similar to Table 7-3 for this analysis.

Table 7-3: Report Format for Token Purchase History Analysis

Feeders	Aging of token purchase history				
	No. of pre-paid consumers	No. of consumers with No-recharge age			
		< 1 month	1-3 months	3-6 months	More than 6 months
Feeder 1					
Feeder 2					
Feeder n					

- *Surveillance and periodic inspections:* With implementation of a pre-payment system, utilities reduce their operating expenditure as meter readers are not required to go to customer premises for meter reading and electricity charges are collected in advance. It also reduces chances of meter tampering that may happen due to connivance between the meter reader and customers. However, the utility loses a tactical tool of revenue protection wherein the meter reading acts as regular periodic surveillance of meter installations. The meter readers may also act as a deterrent against meter tampering and direct theft. They also act as eyes and ears of the utility, passing on critical information to the back-office in suspicious cases.

  After a few months of change from a post-payment to a pre-payment system, customers start observing this change, and the absence of meter readers. Some customers try to take advantage of this situation and start indulging in illegal means of obtaining electricity. For utilities, it is not easy to notice such a situation unless losses are incurred at an alarming pace. LEC seems to be in a similar situation. Thus, utilities need a mechanism to handle such issues and recover from damage already done. PATRP suggests the following two actions to handle the situation:

- *Periodic Meter Readings*: LEC should immediately initiate periodic meter reading of pre-payment installations. The meter readings can be quarterly (preferable) or even once every four months. This will have multiple benefits. First, it will establish the traditional deterrent against meter tampering or illegal theft of electricity. Second, the meter readings brought through this exercise can be compared to the procured recharge token units, thereby helping identify customers that may be indulging in theft. The greater the difference between consumption as per meter readings and coupon purchase the stronger the case for electricity theft. This will provide a much stronger pointer to catch customers indulging in electricity theft.

- *Periodic inspections:* Based on meter readers' feedback, analysis of consumption, analysis of recharge coupon purchase history, and insights from an energy balance system, periodic inspection of installations should be conducted. The inspections could target specific installations based on pointed observations from meter readers and regional staff, or the inspections could cover a small territory based on general trends (reduction in consumption or reduced purchases) observed. Mass inspection of all pre-paid installations is not suggested as it requires large resource mobilization, and maintaining such large initiative is difficult. Rather, inspections covering small territories based on data analysis are more effective.

1.f: Improve pre-payment vending system and corporate branding

Figure 7-5 shows the LEC pre-payment system. As can be seen, the entire vending process (including super vendor ESG and third-party local vendors) is controlled and operated by Itron.

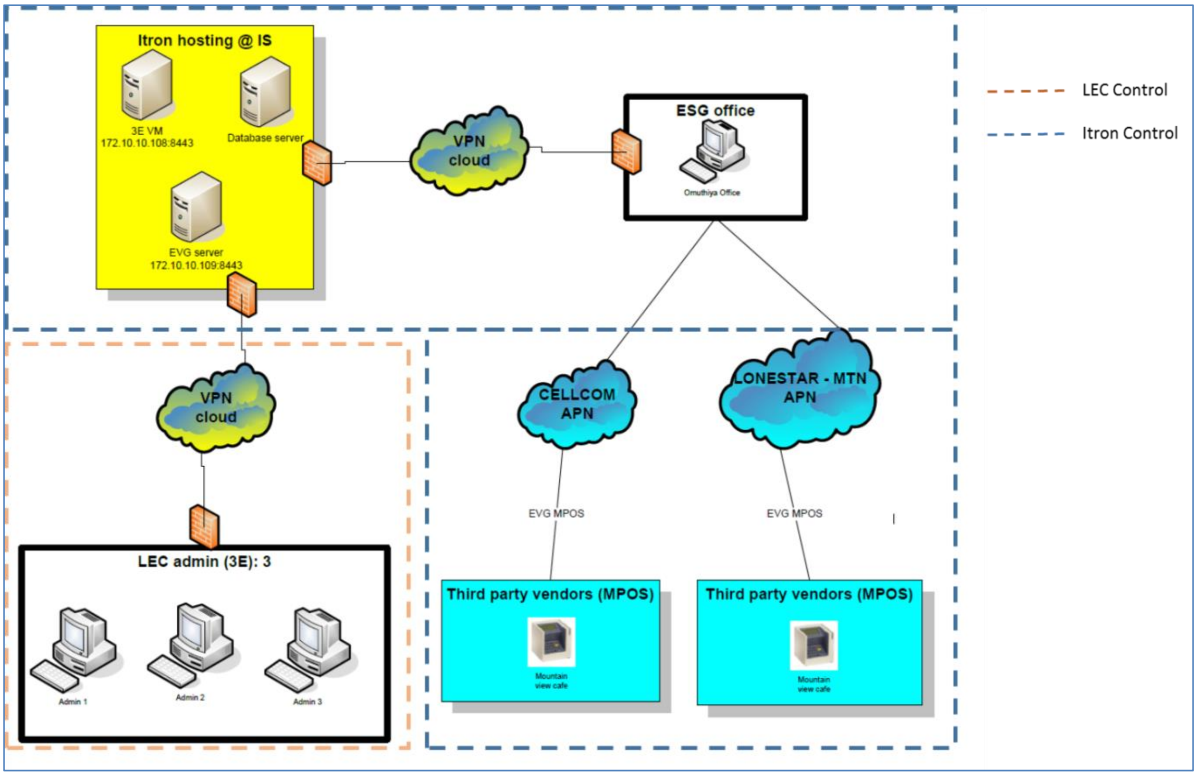


Figure 7-5: LEC Pre-payment metering system

It is not customary for Itron to control vending systems for utilities. This results in high transaction costs (around $0.03 per kWh in LEC's case). PATRP recommends that LEC consider taking over the vending system to reduce transaction costs.

Other advantages of taking over the vending system will be improved customer reach as vendors can act as extension of LEC and can be used for registering customer complaints and resolving basic queries. It will also give LEC the opportunity to improve its corporate branding. **Error! Reference source not found.** shows directions for one of the local vendor offices.

Figure 7-6: Local vendor for recharge token sale

At present, the local vendors cannot use LEC branding as they are not directly associated with LEC.

PATRP expects that the expenses towards takeover of local vendors and corporate branding will not involve any major capital expenditure and can be met through savings from transaction charges, which are expected to be around $0.015 per kWh.

7.2.2 Improve current metering system

PATRP observed major weaknesses in the LEC metering system. Some of the recommendations for strengthening the metering system include:

2.a: Strengthen meter specifications

The present meter specifications for both single-phase and three-phase pre-payment meters is very weak and specifies only basic parameters without much detail. The weak meter specifications are one of the major reasons for high meter fault rate. PATRP recommends that LEC improve its meter specifications at the earliest. The meter specifications should specify in detail at least the following:

- *Functional Requirements*:
    - Tariff Implementation (TOU time zones, lag/lead, peak tariff etc.)

    - Meter memory (load profile, non-interval data storage, real-time clock, calibration test output, communication interfaces)
    - Battery accessibility and replacement
    - Manual meter reading
    - Self-registration of meter with LEC system
- *Anti-tamper features*:
    - Terminal cover open
    - Phase failure
    - Phase voltage loss
    - Phase current loss
    - Current unbalance
    - Reverse current and overload
    - Power breakdown
    - Influence of magnetic field
    - Influence of high frequency, external AC/DC to neutral, or electro static discharge
    - Neutral disturbance
- *Functional requirements for meter's load control capability*
- *Requirements for customer interface unit (CIU) and meter display:*
    - Display parameters
    - Sequence of parameters and programming
- *Communication system requirement:*
    - Communication media
    - Communication protocols
- *Operating environment requirements:*
    - Electrical requirements
    - Appliance control device (disconnecting device)
    - Mechanical and climate requirements
- *Cyber and data security measures*
- *Applicable national and international standards*

If LEC is not able to develop comprehensive meter specifications on their own, PATRP recommends they hire an external consultant for the same.

2.b: Develop and implement a comprehensive meter sealing system

At present, LEC does not have a meter sealing system in place and hence should define seal management policy. The seal management policy should address at least following:

- *Objective* – better revenue protection
- *Tracking* – Inventory management, issuance, life cycle management and disposal (these processes to be handled by specific module within IT system)
- *Usage* – Specify type of seals (lead, plastic steel) for different applications and customer categories
- *SOPs* – Specify sealing positions (meter body, terminal and meter box), sealing sequence (specific pattern to be followed), and correct sealing procedure

- *Adopt different kinds of seals for different applications:* Different utilities follow different sealing practices depending on their requirements and prevalence of tamper activities in their territory. Sealing practices have been improving and evolving with the new tampering activities. Nevertheless, some clear trends are emerging that show utilities doing away with traditional lead seals and adopting versatile plastic and steel seals. In the past, most utilities relied on lead seals with specific signature patterns to be used by a few authorized officials. This worked well when the number of electricity connections were low and meter tampering was rare. Soon, people involved in meter tampering started replicating the signature and employing sophisticated means of tampering seals and meters. In search of better solutions, the electricity industry looked at other sectors such as oil, gas, and transport that employ a variety of seals to protect their goods. Most of the electric utilities are now using plastic seals along with holographic seals. Some utilities also use high-strength steel seals for high-revenue customers. These high-strength steel seals need specialized equipment to cut and remove the seals. Plastic seals provide flexibility to utility in choosing color of seals for different applications. Holographic seals are used for easy detection of any breakage or tamper through void signs and continuity tests. Holographic seals now are used by almost all product companies to protect their brands and products. However, in electric utilities, the experience has been mixed. This is due to the fact that electric meters are installed outside customer premises and exposed to weather, or installed in electric chambers that may be humid and full of dirt. As a result, the holographic seals may wither with time. Moreover, using holographic seals requires that the meter body or box is dirt free and properly cleaned for the adhesive to affix properly. With these insights and experience, PATRP makes following suggestions for LEC:
    - High-strength steel seals for large and high-revenue customers
    - Plastic seals for other customer categories
    - **Blue** for new connections, **green/yellow** for replacements under damaged/faulty/burnt/mass replacement, and **red** for field inspection
    - Test holographic seals and use them in specific cases where a customer is a habitual offender and in large power or high-revenue cases

2.c: Enhance meter testing capabilities

LEC has one portable Zera meter testing instrument, which is used by the Commercial Technical Department for testing three-phase and CT meters. However, it was noted that there is no dedicated computer or server where the data collected during testing can be uploaded and as a result lot of meter test data is being lost due to memory overflow in the instrument. PATRP suggests that LEC should procure two more three phase portable meter testing equipment and five single phase portable meter testing instruments. In addition to the field meter testing equipment, LEC should also set-up a meter testing laboratory which should have at least one three phase (5 position) test bench and one single phase (10/20 position) test bench that can test at least ten single phase meters at a time. The purpose of the field test instruments and the meter testing laboratory are following:

- Test all three phase and single phase meters in the laboratory before they are sent out in the field for installation. The laboratory will put its seal and test results on meter body.
- Test all disconnected, faulty and tampered meters brought back from the field for ascertaining the cause of fault or reduced recording in consumption. This will help in assessing customers for revenue recovery.
- Conduct meter testing in field during inspections to ascertain the working meters.
- Conduct periodic meter testing of three phase and single phase meters at customer premises.

The procurement of field meter testing sets and laboratory testing benches requires substantial investment. The suggested investments in testing equipment are outlined in Table 7-4.

Table 7-4: Investment for testing facilities

Investment	Unit price	No.	2016-17	2017-18	2018-19	2019-20	2020-21	Total
Single-phase portable test set	$15,000	5	$30,000	$45,000				$75,000
Three-phase portable test set	$25,000	2	$50,000					$50,000
Single-phase multi-position (10/20 positions) laboratory test bench	$200,000	1	$200,000					$200,000
Three-phase multi-position (5 positions) laboratory test bench	$250,000	1		$250,000				$250,000
Laboratory space upgrade	$50,000	1	$50,000					$50,000
Total			**$ 330,000**	**$295,000**				**$625,000**

It is assumed that LEC has space for the laboratory in one of its buildings and expenses will be dedicated to upgrading that space to make it suitable for a laboratory.

7.2.3 Implement Automated Meter Reading (AMR)

As LEC moves towards acquiring more large customers and implementing an energy balance system, it is recommended that an AMR system is also implemented to increase operational efficiency, reduce billing errors, and improve revenue protection. For a small system like LEC, the AMR system should be fairly simple, as shown in Figure 7-7.

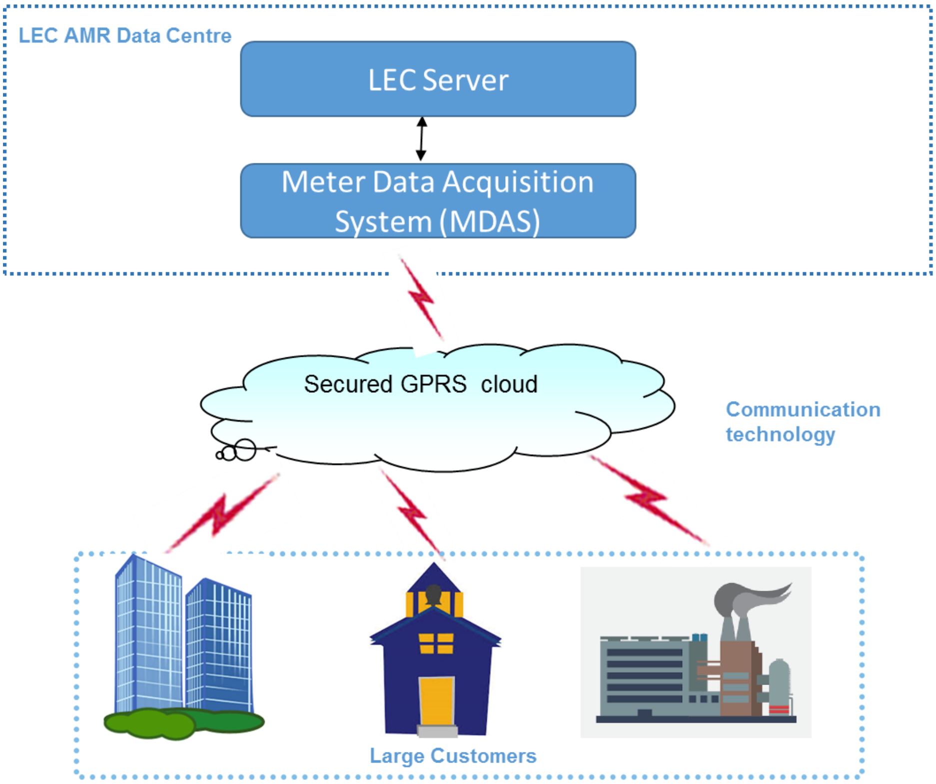


Figure 7-7: Simplistic view of LEC AMR architecture

LEC indicated that electronic meters installed at large customers have the ability to communicate over GPRS. In case some meters are not GPRS-enabled but instead have optical ports for communication, modems can be used to send data from the meters via a GPRS network. At present, LEC has approximately 354 post-paid customers and 67 more are expected to be recruited soon. Around 500 AMR-enabled meters can be connected for energy balance activity. Based on the success of the AMR in large customers and energy balance, LEC may choose to roll-out AMR for more customers in residential and commercial segments that have consumption of around 500kWh per month. With these considerations, an AMR system should be designed to cater to a meter population of 5,000. This size of AMR system is considered small and costs should not be high. In fact, LEC can negotiate with current meter vendors to provide the AMR system at reasonable costs. The total investment cost for the AMR system should not be more than $250 per customer connection. The expected investment in the system is shown in Table 7-5 below.

Table 7-5: Investment for AMR system

Investment	Unit price	Nos.	2016-17	2017-18	2018-19	2019-20	2020-21	Total
AMR system (including hardware, software and back-end system)	$1,250,000	1		$1,250,000				
Total				**$1,250,000**				**$1,250,000**

It is assumed that the operational cost of the system, including maintenance and GPRS data charges, will be met from LEC operational expenses.

7.2.4 Implement Energy Balance system

Establishing an energy balance system is essential for keeping account of electricity being delivered to various network points or to different regions in the LEC service area as compared to the revenue collected. This entails installation of energy meters at generators, transmission feeders, distribution feeders, and distribution transformers. Electricity delivered to different feeders or regions is compared with the electricity billed to customers in those feeders/regions and overall system losses are estimated. Based on the loss estimates, the utility identifies the high-loss feeders or regions and initiates actions for loss reduction. The same exercise is repeated on each feeder by comparing energy delivered to each distribution transformer and electricity billed to customers connected to that particular transformer. High-loss distribution transformers are thus identified and appropriate revenue protection activities initiated. The investment required in energy balance activity is shown in Table 7-6 below.

Table 7-6: Investment for energy balance system

Investment	Unit price	No.	2016-17	2017-18	2018-19	2019-20	2020-21	Total
Energy metering at generating units	$500	22	$11,000					$11,000
Energy metering at 66kV and 22kV	$10,000	11	$110,000					$110,000
Distribution transformer metering	$500	450	$50,000	$50,000	$75,000	$75,000		$250,000
Customer mapping and enumeration	$2	37,000		$40,000	$34,000			$74,000
Total			**$ 160,000**	**$90,000**	**$109,000**	**$75,000**		**$434,000**

Some considerations for estimating the above investment:

- At present, 22 X 1 MW generating units have been considered for energy metering and it is assumed that all upcoming generating units will have energy metering provisions.
- There are eight 22kV feeders and three 66kV feeders that need to be metered to create energy balance HV and MV levels.
- There are 1,842 distribution transformers in LEC, of which 540 are three-phase transformers. As per data in LEC IT system, around 90 three-phase transformers have energy meters, some of which may be electro-mechanical meters but can be replaced with existing stock of three-phase meters.

Thus, only 450 three-phase transformers need to be metered. It is suggested that individual single-phase transformers should not be metered, rather one meter at MV level can be installed for each community and suitable arrangements can be made based on ground conditions. After completion of the three-phase metering, the separate communities can be metered.

7.2.5 Procure a comprehensive commercial IT system

Most of the business processes, specially related to metering, billing, collection and customer care are manual causing delays and lack of adequate monitoring and control. Similar weakness is observed on the network management side as well. It is worth noting as this point, that LEC had initiated procurement of a comprehensive IT system 2012 but the same has not been procured among various reasons due to lack of funds. PATRP has been informed that the World Bank is supporting LEC in procuring the IT system. The envisaged IT system is shown in Figure 7-8.

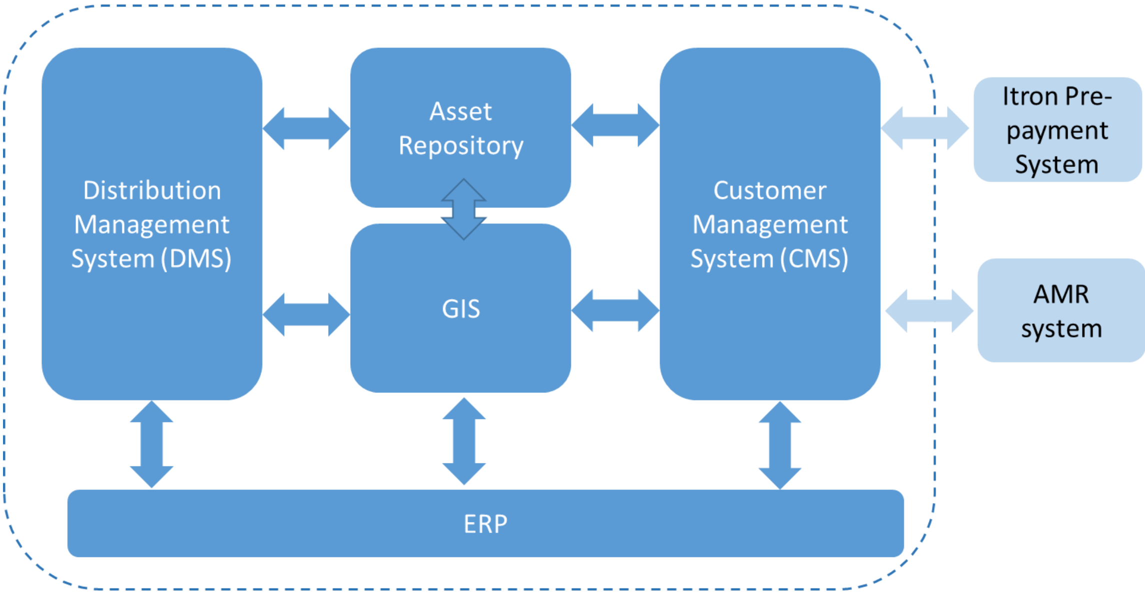


Figure 7-8: IT system being procured in LEC

The market has already been tested as proposals were invited for the IT system. The investment needed for the IT system based on the previous procurement is shown in Table 7-7 below.

Table 7-7: Investment for IT system

Investment	Unit price	Nos.	2016-17	2017-18	Total
IT System (DMS,CMS,ERP)	$12,000,000	1	$6,000,000	$6,000,000	
Total			**$6,000,000**	**$6,000,000**	**$12,000,000**

The priority of implementation of different systems should be as follows:

1. Implement CMS and ERP
2. Integrate CMS with AMR, Itron Pre-payment system and GIS
3. Implement DMS

7.2.6 Improve fuel accounting system

LEC loses the equivalent of approximately 11 days of fuel annually (refer to Table 6-1) for various reasons, including different measurement methods adopted for measuring supply and consumption of fuel, defective flow meters, non-calibration of flow meters, and uncleaned fuel tanks. PATRP suggests the following interventions to improve the fuel accounting system:

- Periodic cleaning of fuel tanks
- Periodic testing and calibration of fuel meters
- Replacement of faulty flow meters

PATRP does not see a significant investment in these interventions and the expenses can be met through LEC operational expenditure.

7.2.7 Capacity Building

Capacity building should be one of the main focus areas for LEC. PATRP observed significant weaknesses in the competence of LEC staff in all key functions, including commercial, network management, and generation, primarily due to lack of exposure and training. Some of the staff that underwent training did not receive sufficient hands-on practice on the tools, making the training ineffective. For instance, many engineers in the Planning Department underwent training for GIS and network modelling. Both these aspects were crucial for completion of this assignment as LEC network mapping had to use already existing ArcGIS® software, and technical loss estimation needed modelling and simulation on ETAP®. However, the engineers trained on these tools never used these tools in day-to-day activities. The PATRP team put considerable efforts into training these engineers again so that the tasks could be completed within defined timelines.

Based on the insights gained during this assignment, PATRP recommends following areas for capacity building:

- *Revenue protection*: Revenue protection training should include at least the following:

    - Procedures for analyzing meter data and corroborating the findings with LEC system data.
    - Types of tampering in meters and procedures for identification.
    - International best practices for improving meter security, including meter design, meter testing, and meter sealing procedures.
    - Exposure visits to utilities that have reduced energy theft through innovative revenue protection interventions.

- *Commercial processes* : Commercial processes are key to financial sustainability of utilities and this training should include:

    - Latest trends and innovations in metering, billing and collection processes.
    - Meter technologies, AMR/AMI, communication technologies.
    - Effective use of commercial IT systems, such as customer management systems (CMS), meter data management, GIS, and inventory systems.
    - Energy balance calculations, troubleshooting, and customer enumeration procedures.
    - AT&C loss calculations, estimate of technical and non-technical losses.
    - Customer care procedures and customer outreach.
    - Exposure visits to international benchmark utilities to learn about their organizational commercial structure.

- *Geographical Information System (GIS)*: Some engineers have been trained on ArcGIS® software available within LEC, but they will need continued training to hone skills. This training should focus on:
    - Procedures for collecting data, geo-referencing network equipment and data upload to LEC server(s).
    - Procedures for updating ArcGIS® maps, distance measurements, creation of layers.
    - Import and export data from different sources.
    - Use of GIS system in commercial and network operations.

- *Network modelling and simulation:* LEC has ETAP® and CYMDIST for network modelling, but neither are being utilized. The PATRP team used ETAP® to model the LEC network and trained two engineers during the process. However, these engineers need to be provided more training to gain expertise. More engineers must be trained in this area as modelling and simulation are essential for system planning. Some key aspects to be covered in the training are:
    - Training on operation and use of ETAP® and CYMDIST.
    - Development of system models, power flow, and transient analysis.
    - Estimation of system augmentation and extension needs.
    - System load analysis to identify network constraints.
    - Development of integrated system plans.

- *O&M and Safety*
    - Operation and maintenance of generating plants.
    - Operation and maintenance of transmission and distribution network.
    - Maintenance schedule preparations and planning.
    - Safety procedures.

The abovementioned trainings can be provided at LEC, or staff can be sent to recognized training centers and utilities in other countries. Subject experts from other countries can be invited to impart training to LEC staff. Some of the staff should be groomed as master trainers who can in turn train other staff in LEC.

One of the key constraints LEC faces is a lack of a fully equipped training center. PATRP recommends that a fully equipped 'LEC Training Center' be developed at one of the existing substations or generating stations where sufficient land is available for developing such a facility. Housing the training center at a substation or generating plant will ensure that trainees can receive both classroom as well as in-field training at the same location. PATRP estimates the cost of building such a facility to be $1-2 million. During the first two years after establishment of the training facility, training by external faculties or subject matter experts would be needed to develop master trainers in LEC. PATRP estimates that about two hundred man-days (including content preparation and training delivery effort) of external subject matter experts will be needed in the first two years and this effort will be reduced in subsequent years as master trainers start developing within LEC. This effort excludes the trainings provided by equipment and product suppliers as part of their contracts.

The investment required for establishing the training center and arranging external subject matter experts for training is provided in Table 7-8 below.

Table 7-8: Investment for training

Investment	2016-17	2017-18	2018-19	2019-20	2020-21	Total
Create 'LEC Training Center'		$3,000,000				$3,000,000
External subject matter expert costs		$421,300	$421,300	$210,650	$105,325	$1,158,575
Total		**$3,421,300**	**$421,300**	**$210,650**	**$105,325**	**$4,158,575**

7.3 INVESTMENT PLAN

Based on the discussions in the previous section, the investments for recommended initiatives are consolidated in Table 7-9 below.

Table 7-9: LEC investment requirement

Investment	2016-17	2017-18	2018-19	2019-20	2020-21	Total
Enhance meter testing capabilities	$ 330,000	$295,000				$625,000
Implement AMR system		$1,250,000				$1,250,000
Implement Energy Balance System	$ 160,000	$90,000	$109,000	$75,000		$434,000
Procure comprehensive IT system	$6,000,000	$6,000,000				$12,000,000
Capacity building		$2,421,300	$421,300	$210,650	$105,325	$4,158,575
Total	**$6,490,000**	**$10,056,300**	**$530,300**	**$285,650**	**$105,325**	**$17,467,575**

It should be noted that the above table shows investment for only those priority actions that will need external funding support. PATRP believes that many priority actions related to restructuring of the Commercial Department, improvement in fuel measurement and accounting system, and implementation of commercial processes can be funded by LEC internal resources.

PATRP estimates that LEC needs to invest around $17.5 million in the coming five years in loss reduction to make the utility sustainable. Some of the investments included in the above table are already under some form of consideration and should be expedited. For instance, the World Bank is already supporting the procurement of a comprehensive IT system, and MCC is already working on setting up a training center within LEC. If it is assumed that World Bank and MCC funding will sufficiently cover the IT systems and capacity building requirements respectively then only $2.3 million will be needed for other initiatives. For other investments, LEC should work with the donor partners already involved in the sector.

These investments will equip LEC with the necessary systems, processes and tools to help reduce AT&C losses and make the operations sustainable. While prioritizing the recommended priority actions and investments, LEC should start by restructuring the organizational structure to bring focus on AT&C losses reduction. The restructuring should be accompanied by establishment and institutionalization of energy balance system. Energy balance system will provide information on the high losses areas in LEC for targeted losses reduction actions. Improvement in metering system including strengthening meter specification , developing a meter sealing system and increasing meter testing capabilities are essential steps to support the loss reduction actions and can be prioritized to be implemented in identified high loss areas in LEC. As back bone of all commercial functions and loss reduction activities, a strong commercial IT system, provides capabilities for tracking, monitoring and controlling commercial processes and hence is essential for LEC's operational sustainability. A comprehensive IT system is under procurement at LEC and steps should be taken to ensure timely procurement and implementation of its various modules as described in section 7.2.5.

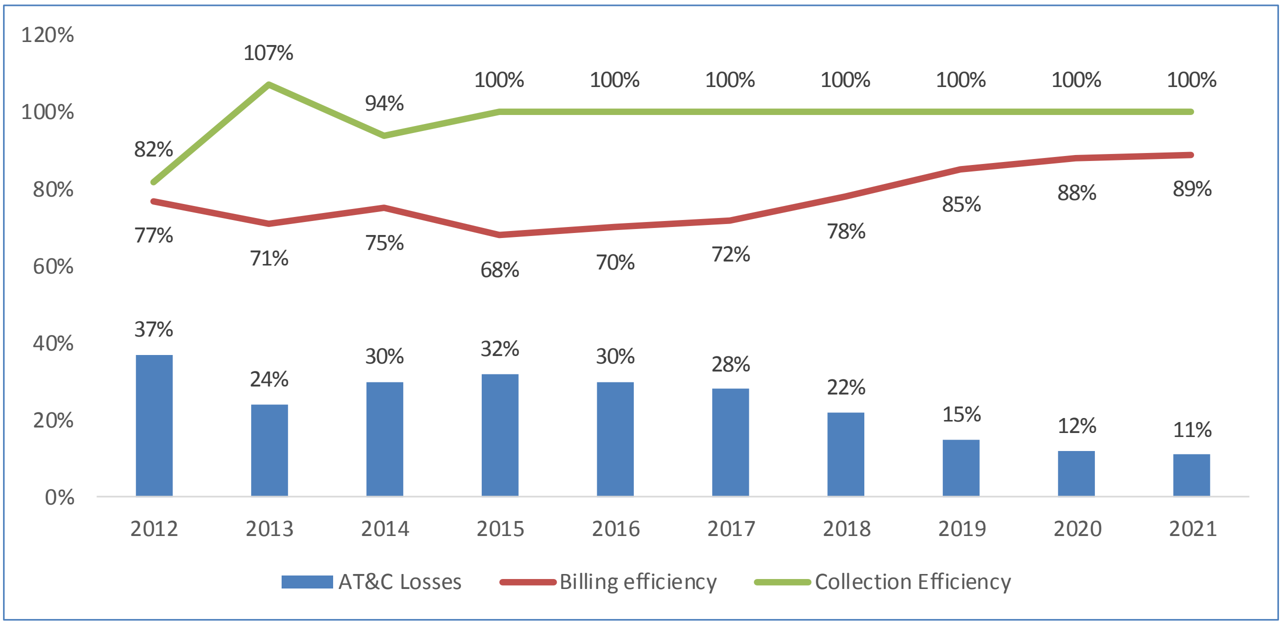


Figure 7-9: LEC losses reduction trajectory

The fuel measurement and accounting system also needs to be improved to prevent against possibility of fuel theft. PARTP believes that the planned new fuel supply and piping system at Bushrod Island will address all the issues discussed in section 6 and section 0.

Capacity building of LEC staff is a major priority. LEC needs to build a training center that can be used to provide both classroom and hands-on training to its staff. LEC should take help of external subject matter experts to develop master trainers who in turn will build capacity of other staff. Focus areas for capacity building are discussed in section 7.2.7.

PATRP believes that with implementation of recommended Priority Actions, LEC will be able to reduce AT&C losses to a level of 11%-12% in coming four years. As more than 95% customer connections are planned to remain on pre-paid metering system, the collection efficiency will be around 100% in coming years as well. The billing efficiency will improve over the years as the recommended initiatives are implemented. It may appear that four years is a long time frame for reducing losses to 11%-12% for a small utility with just 36,000 connections. However, it should be considered that LEC plans to double its customer base every year for the next couple of years expanding its services to areas beyond

Greater Monrovia region. This expansion will have bearing on the resources available for implementing the priority actions. The current management contract for LEC is coming to an end in December 2016 and a new management contractor will start services towards mid of 2017. This transition may slowdown the implementation of some of the priority actions. Thus, the actual impact of losses reduction will be visible from financial year 2018.

8. APPENDIX

8.1 MODELED ONE-LINE DIAGRAMS OF LEC SYSTEM AND SUBSYSTEMS/COMPOSITE NETWORKS

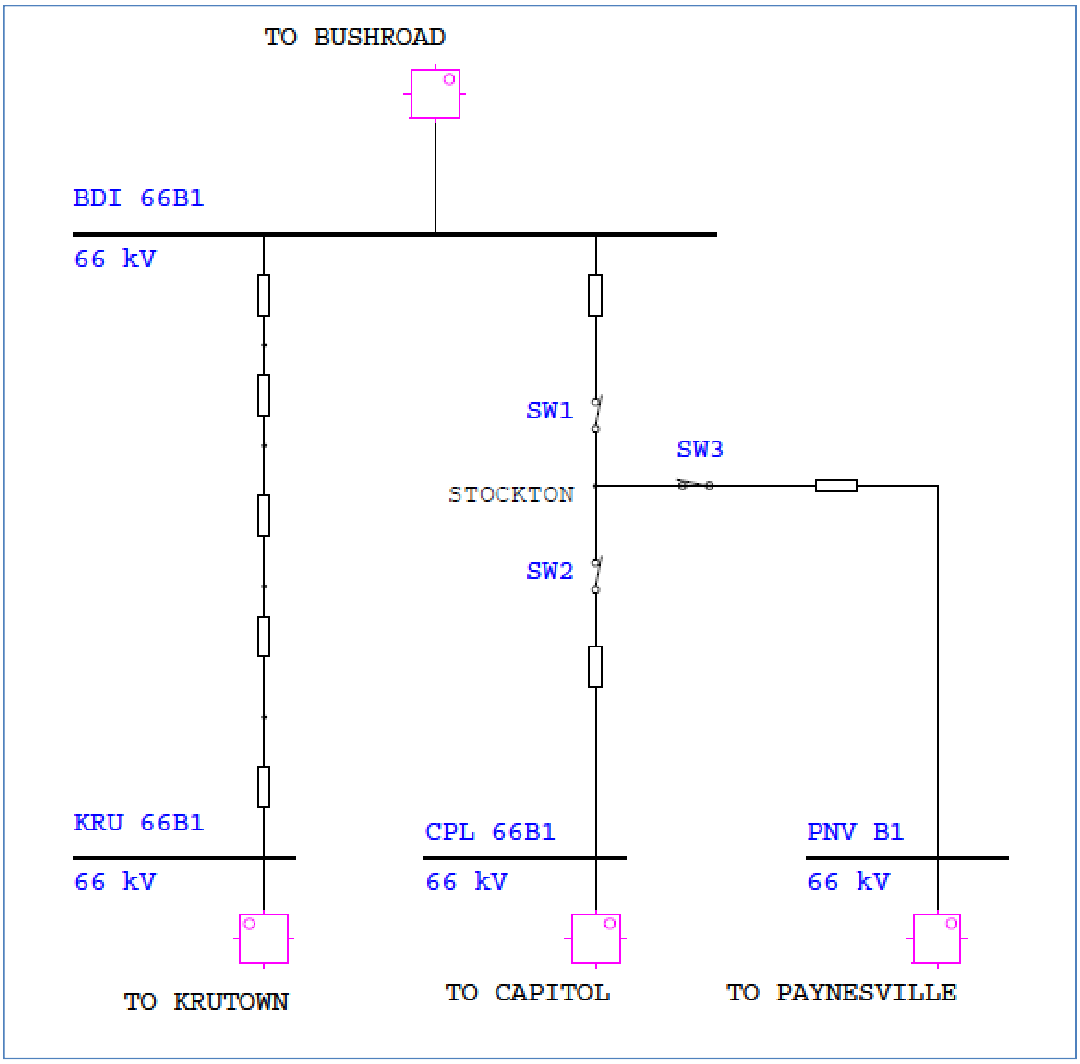


Figure 8-1: LEC System Model: One-line diagram of Transmission with composite networks

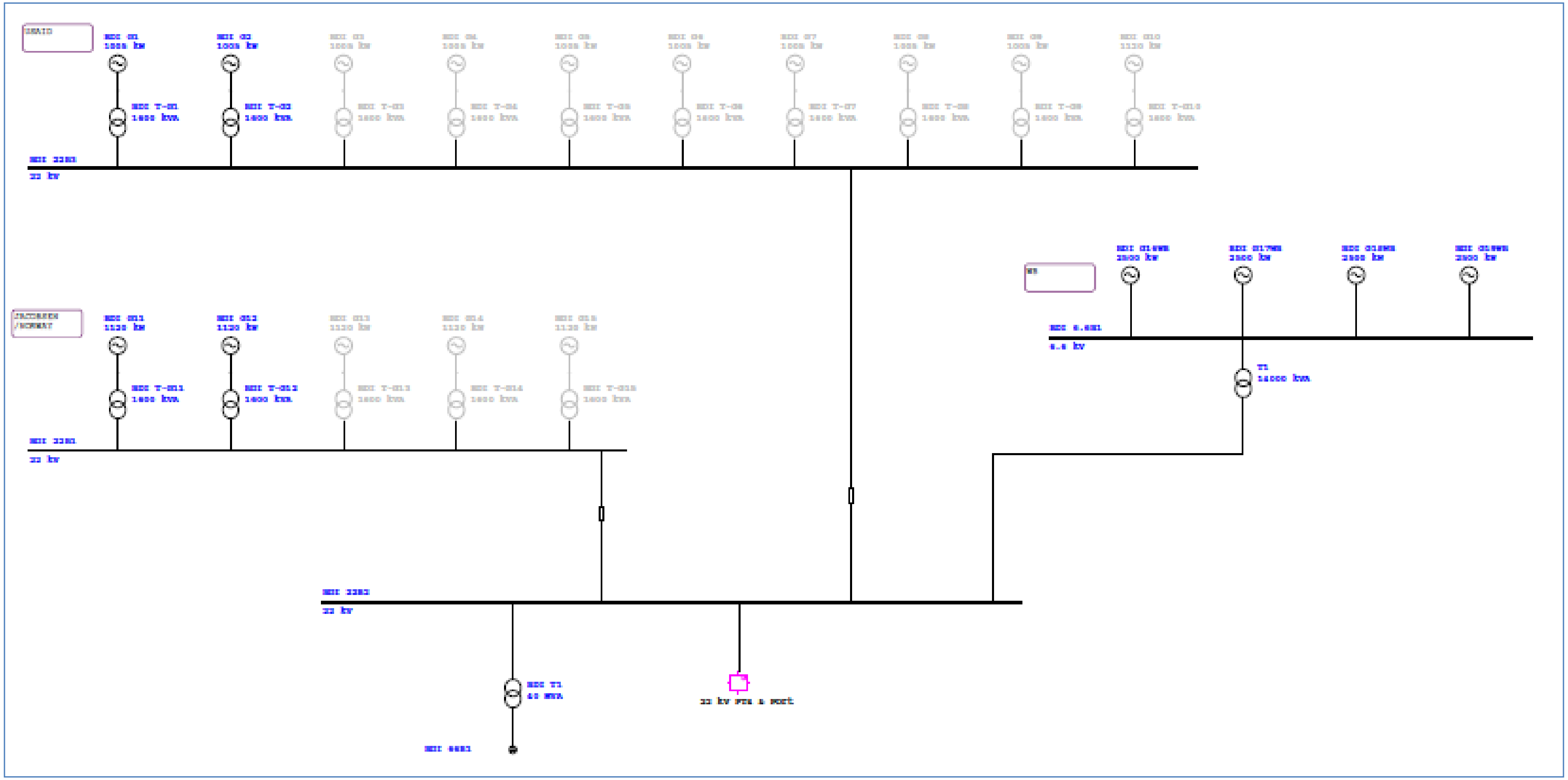


Figure 8-2: Bushrod Generating Plant & Substation

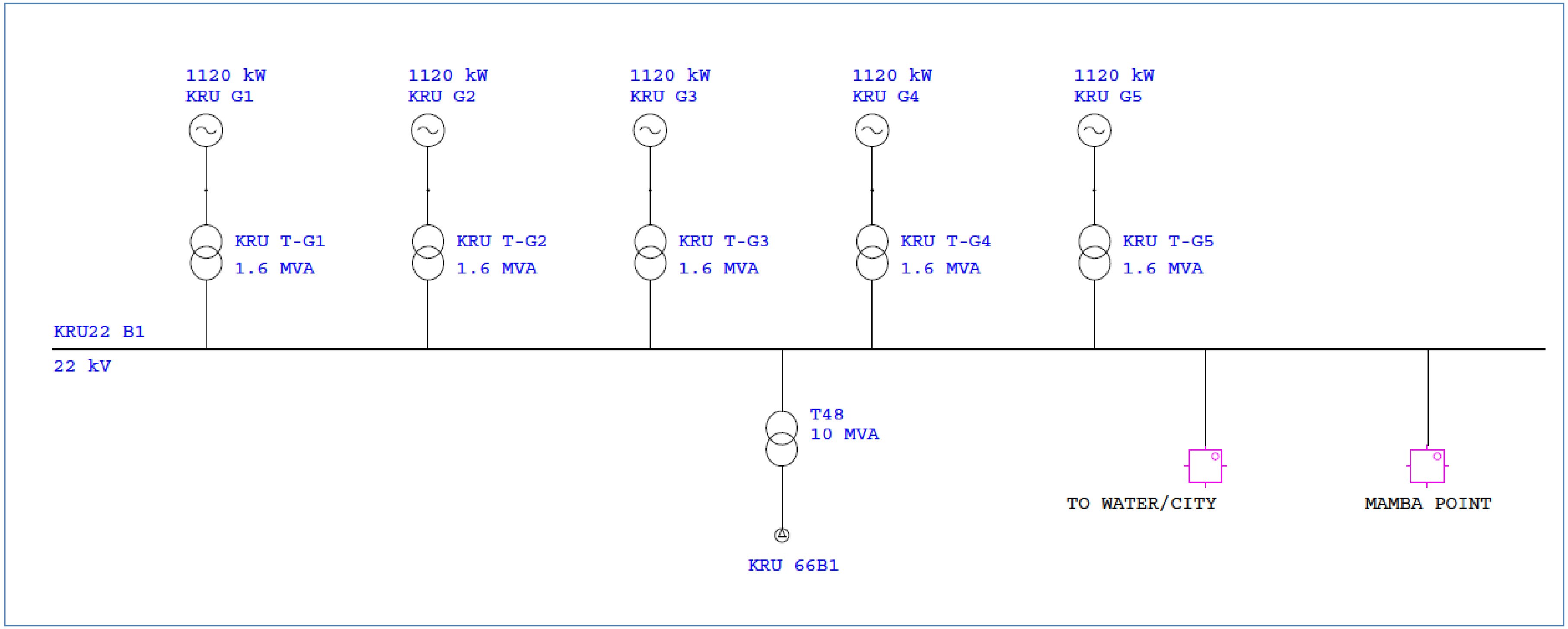


Figure 8-3: Kru Town Generating Plant & Substation

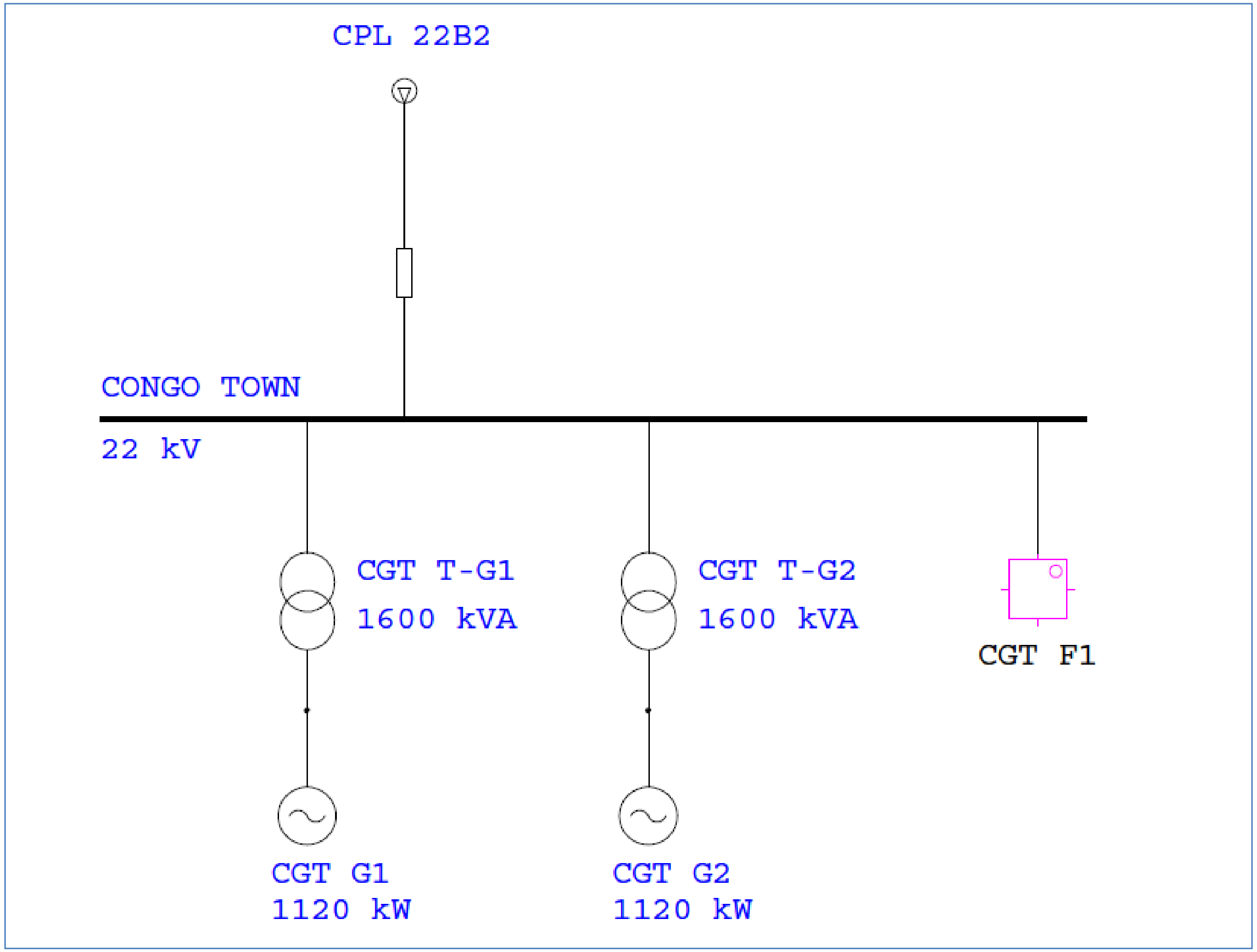


Figure 8-4: Congo Town Generating Plant & Substation

8.2 MODELLED MV AND LV NETWORK

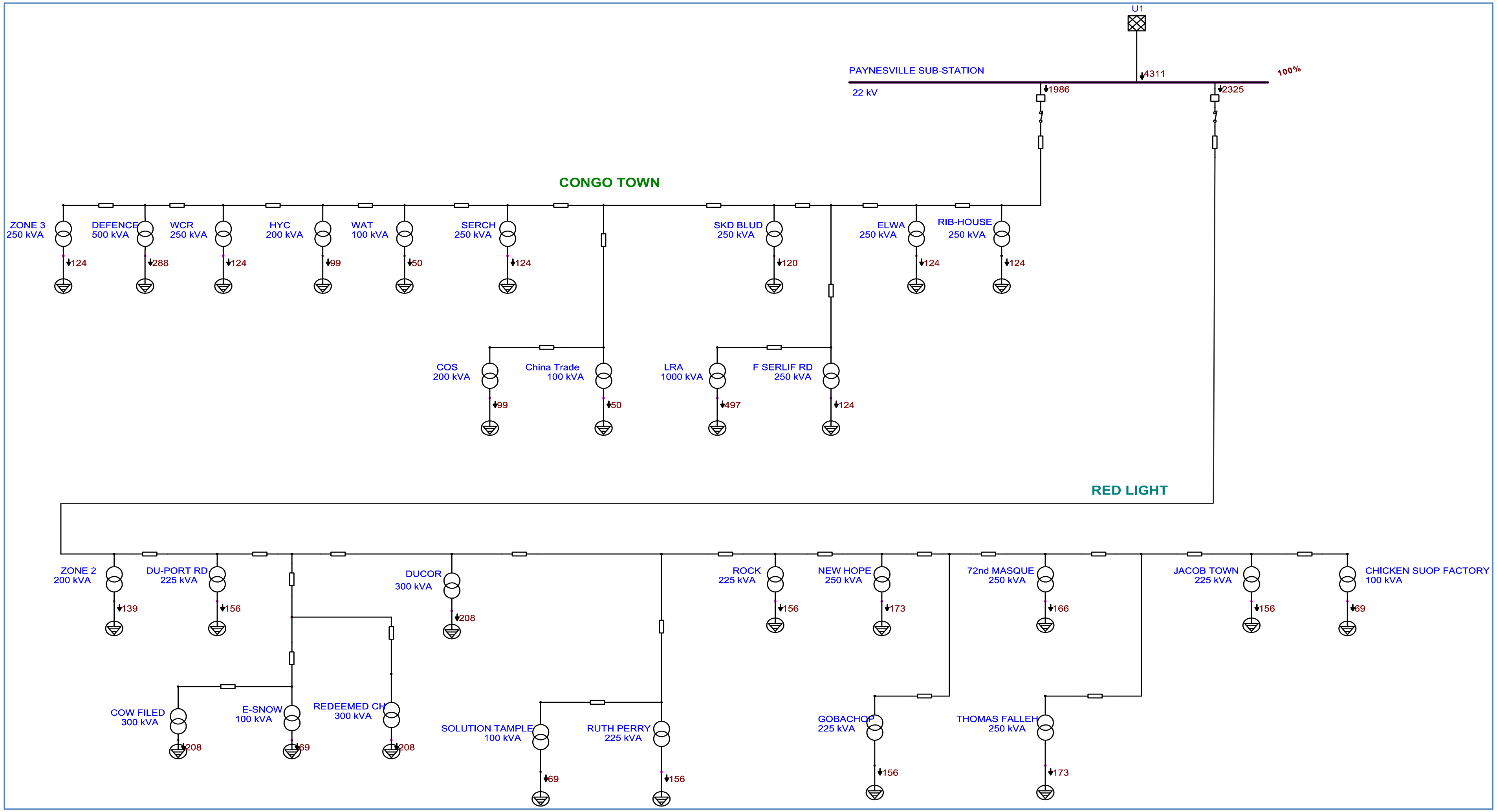


Figure 8-5: Model of outgoing distribution feeders from Paynesville S/S

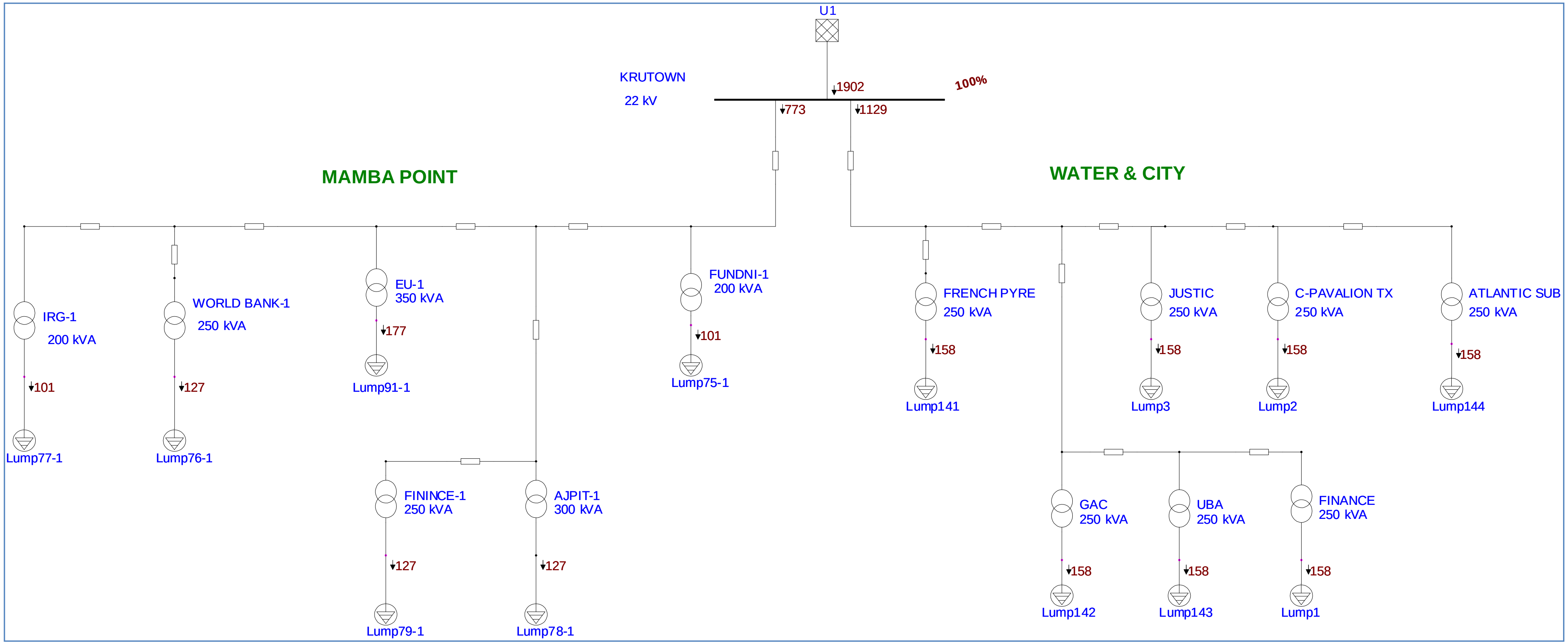


Figure 8-6: Model of outgoing distribution feeders from Kru Town S/S

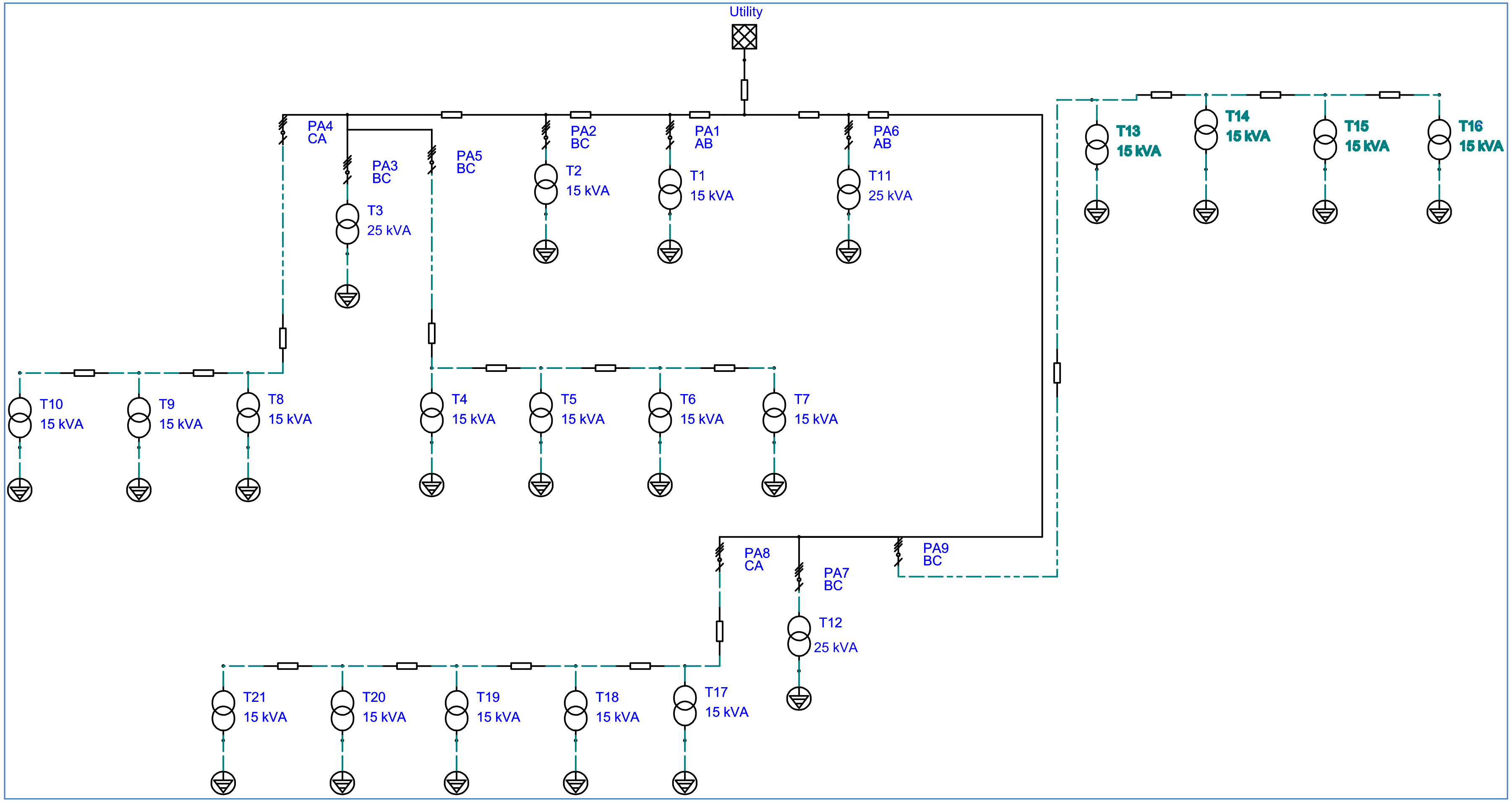


Figure 8-7: Model of a sample two wire/single phase feeder (an outgoing feeder from Bushrod S/S)